# PROPOSAL SUBMITTED IN RESPONSE TO NRA-03-OSS-01-HCIPE RESEARCH OPPORTUNITIES IN SPACE PHYSICS - 2003

| | |
|---|---|
| **PROGRAM ELEMENT:** | High Capability Instruments for Planetary Exploration |
| **RESEARCH TECHNIQUE/AREA:** | Instrument Development |
| **TITLE:** | In-Situ and Remote Sensing of the Jovian Environment Using Low Energy (1 eV-4 keV) Plasma and Neutral Atom Imaging |
| **PRINCIPAL INVESTIGATOR:** | Michael R. Collier<br>NASA/Goddard Space Flight Center<br>Interplanetary Physics/Code 692<br>Greenbelt, Maryland 20771<br>(301)286-5256 (office)<br>(301)286-1433 (facsimile)<br>michael.r.collier@gsfc.nasa.gov |
| **CO-INVESTIGATORS:** | Edward Sittler, NASA/GSFC<br>Dennis Chornay, NASA/GSFC<br>John F. Cooper, NASA/GSFC<br>Michael Coplan, University of Maryland<br>Robert E. Johnson, University of Virginia |
| **PROPOSED DURATION:** | Three Years (FY05-07) |
| **DUNS NUMBER:** | 136954604 |

| **BUDGET SUMMARY:** | FY05 | FY06 | FY07 | TOTAL |
|---|---|---|---|---|
| **COST:** | $141.0K | $142.7K | $132.9K | $416.6K |

**AUTHORIZING OFFICIAL:**

______________________ ________

Jonathan F. Ormes Date
Director of Space Sciences/Code 600
NASA/Goddard Space Flight Center
Greenbelt, Maryland 20771
(301)286-5705

**PROPOSAL SUMMARY**

| | |
|---|---|
| TITLE: | In-Situ and Remote Sensing of the Jovian Environment Using Low Energy (1 eV-4 keV) Plasma and Neutral Atom Imaging |
| SHORT TITLE: | Jovian Plasma and Neutral Atom Imaging |
| P.I./Institution: | Michael R. Collier/NASA Goddard Space Flight Center |
| Co-I./Institution: | Edward Sittler/NASA Goddard Space Flight Center<br>Dennis Chornay/NASA Goddard Space Flight Center<br>John F. Cooper/NASA Goddard Space Flight Center<br>Michael Coplan/University of Maryland<br>Robert E. Johnson/University of Virginia |
| PRIMARY TYPE: | Instrument Development |
| MISSION TARGET: | Jupiter Icy Moons Orbiter |
| NEPP-Enabled Objectives: | High Resolution Low Energy Neutral Atom Imaging of the Jovian System |
| TRL of Proposed Instrument: | 6 (system model demonstration in space environment) |

We propose developing an instrument suitable for the Jovian environment which is capable of functioning as either a low energy neutral atom imager or as a positive ion spectrometer/neutral atom imager by changing voltages applied to various parts of the instrument. The instrument will employ conversion surface technology and be sensitive to either neutrals converted to negative ions or neutrals converted to positive ions (and positive ions themselves) depending on the power supply. On an actual mission, such as the Jupiter Icy Moons Orbiter (JIMO), two back-to-back sensors would be flown with separate power supplies fitted to the neutral atom and ion/neutral atom sides, which will allow both imaging of neutral clouds and in situ measurements of the plasma environment within Jupiter's magnetosphere. This imager, which will cover the energy range from $1\mathrm{eV}<E<4\mathrm{keV}$, will provide global images of the interaction between the Galilean moons and Jupiter's magnetosphere by measuring the neutrals coming from the icy moons and observing the ion component within the interaction regions of the various moons, for which pickup ions will give information about surface composition. These observations will also allow us to measure the exospheric atmospheres (corona) of these moons and to directly measure their surface composition by detecting the energetic ($>1$ eV) sputtered neutrals of trace elements. These data will be analyzed using Monte Carlo simulations of atmospheres produced by sputtering and radiolysis of proposed surface materials. This instrumentation will also measure the global environment of neutral clouds and plasmas within Jupiter's magnetosphere, which can be traced to both internal and external sources, and provide the boundary conditions for the icy moon interactions with Jupiter's magnetosphere. The proposed instrumentation would provide composition measurements of the neutrals and ions that enter the spectrometer with a mass resolution $M/\Delta M \sim 9$ and be capable of resolving molecules. Among the technical challenges, high-power heaters will need to be mounted to the conversion surfaces and triple coincidence measurements will need to be employed to suppress the high background noise from the harsh Jovian radiation environment. Also, increased sensitivity and geometric factor will be required for sufficient statistics and instrument image cadence along with correspondingly high telemetry rates.

**TABLE OF CONTENTS**

**SUMMARY OF PERSONNEL AND WORK EFFORTS**

| | FY05 | FY06 | FY07 |
|---|---|---|---|
| Collier (PI) | 0.10WY | 0.10WY | 0.10WY |
| Sittler (Co-I) | 0.05WY | 0.05WY | 0.05WY |
| Cooper (Co-I) | 0.05WY/$7.4K | 0.05WY/$8.9K | 0.05WY/$9.9K |
| Chornay (Co-I) | 0.13WY/$16.9K | 0.13WY/$16.4K | 0.13WY/$16.4K |
| Coplan (Co-I) | 0.06WY/$15.5K | 0.06WY/$15.0K | 0.06WY/$15.0K |
| Johnson (Co-I) | 0.10WY/$20K | 0.10WY/$20K | 0.10WY/$20K |
| Rozmarynowski (mech/tech) | 0.10WY | 0.10WY | 0.10WY |

The salaries and costs associated with the Principal Investigator as well as Sittler and Rozmarynowski are supported by GSFC and do not require funding by NASA Headquarters. However, they have been fully costed in this proposal.

## INTRODUCTION

### i. Overview

*The Solar System Exploration Survey New Frontiers Program for the next decade advocated the flagship mission Europa Geophysical Explorer (EGE). This mission has now been replaced by its equivalent Jupiter Icy Moon Orbiter (JIMO)/ Prometheus, for which the latter is a technology demonstration mission for space fission reactors. This mission has its own instrument development program called Hi-Cap and for which we are proposing a* ***Low Energy (1 eV-4 keV) Jovian Ion and Neutral Atom (LEJINA)*** *imaging instrument. This new design does require considerable power during phases when its conversion surface needs upgrading. Higher power levels will also be required since "hot" or "EDR" microchannel plates will be used for a high counting rate capability and the proposed electronics will require high speed (sub-nanosecond) rad-hard electronics which may also require high power levels. This instrument will generate telemetry rates greater than 16 kbps.*

NASA is currently planning an ambitious mission to orbit three of the Jovian Galilean satellites: Callisto, Ganymede and Europa. This mission, the Jupiter Icy Moons Orbiter (JIMO), is designed to determine their makeup, their history and their potential for sustaining life. It will provide many months in orbit around each moon and will allow long-term surveys of magnetic field, plasma, energetic particles, neutral gas, dust and electromagnetic components of the local moon environments and the large-scale magnetosphere. This mission will be enabled by the pioneering use of electric propulsion powered by a nuclear fission reactor and is motivated, in part, by magnetometer evidence from the Galileo Orbiter mission for subsurface oceans of Europa and Callisto [Khurana et al., 1998; Kivelson et al., 1999, 2000; Zimmer et al., 2000] and of Ganymede [Kivelson et al., 2002]. Surface geologic evidence for a modern Europa ocean is compelling but not definitive [Carr et al., 1998; Pappalardo et al., 1999].

Neutral atom imaging may hold the key to answering many of the questions that still remain

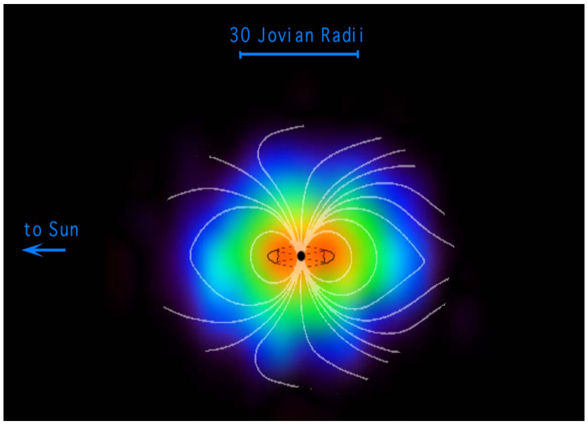


Figure 1. A Cassini/INCA neutral atom image of the Jovian magnetosphere taken shortly after Cassini's closest approach to Jupiter.

following Galileo. With neutral atom imaging, the neutral products of charge exchange reactions or sputtering processes are sampled from a remote location. This technique is different from but complementary to *in-situ* neutral gas observations because it is sensitive to individual atoms and molecules, provides a global perspective of plasma and erosion processes and allows a sampling of regions the spacecraft does not or cannot traverse.

Figure 1 shows an Ion-Neutral CAmera (INCA) [Mitchell et al, 1993] image of the Jovian magnetosphere taken shortly after Cassini's closest approach to Jupiter. INCA responds to high energy neutral atoms (>20 keV), and this image shows the nebula of Iogenic neutrals which surrounds Jupiter.

However, most of the plasma in the heliosphere lies below a few kilovolts in energy and much of the plasma and neutrals of scientific interest at Jupiter lie in this energy range. For example, neutrals sputtered off satellites will be primarily in the <10 eV energy range [Johnson, 1990]. Even neutrals generated in the Io torus where oxygen and sulfur ions almost fully corotate at about 60 km/s will have energies of about 300 and 600 eV, respectively. Even many tens of Jovian radii away from the Io torus, the Jovian plasma appears to corotate at around half the rigid corotation speed [Kane, 1991; McNutt et al., 1979].

Thus, in order to fully and effectively explore the Jovian environment, **low energy neutral atom imaging** must be a major instrumental component of any planned mission.

**ii. Objectives and Scientific Significance**

The objective of the first year of this study is to define and develop subsystems of a low energy plasma spectrometer and neutral atom imager suitable for the Jupiter Icy Moons Orbiter which can:

***•Remotely image eV to keV neutrals from Jovian magnetospheric interactions with the neutral atmospheres, ionospheres, and surfaces of the icy Galilean moons, and measure in-situ pickup ions in the magnetospheric wakes and jovicentric orbital tori of the moons. Since the atmospheric, ionospheric, and wake composition mostly arises originally from surface sputtering by magnetospheric ions, all LEJINA neutral and ion measurements near the moons will provide new information on composition of the moon surfaces.***

***•Remotely image the temporal variation of neutral atom spatial distributions around the icy Galilean moons for correlation to magnetic field and ionospheric structures varying in response to the Jovian background magnetospheric field, any intrinsic field and its potential secular variation (Ganymede), and induced fields from subsurface oceans.***

***•Identify the presence of selected neutral and ionic molecules within the expected range of LEJINA mass resolution in the vicinity of the Galilean moons and Jupiter's magnetosphere in general.***

The objective of the second year of the study is to further refine the instrument design and integrate and test the subsystems.

The objective of the third year is to produce an integrated fully-operational prototype of a low energy neutral atom imager/ion spectrometer suitable for the Jovian Icy Moons Orbiter mission.

For the JIMO mission our spectrometer can provide composition measurements of large scale neutral clouds and plasma populations within Jupiter's magnetosphere. It will also be able to image Jupiter's polar ionosphere, measure precipitating ions and their composition along auroral field lines and the precipitation of heavy ions at lower latitudes where the thermosphere is hotter than its surroundings [Waite et al., 1983, 1994, 1996, 1997; Seiff et al., 1996; Metzger et al., 1983; Cravens et al., 1995; Drossat et al., 1993; Sommeria et al., 1995] and the field lines map to the radiation belts of Jupiter. Possible ions are $H^+$, $H_2^+$, $H_3^+$, $O^+$, $O^{2+}$, $S^+$, $S^{2+}$, $S^{3+}$, and $SO_2^+$ among others. These ions will be observable because of Jupiter's extended hydrogen corona.

This instrument will also be able to image the hot Io torus and since it can measure neutrals down to 1 eV, it will also be able to image the cold Io torus. Because Io is clearly the major source of plasma, energetic particles and neutrals within Jupiter's magnetosphere [Belcher, 1983; Krimigis and Roelof, 1983; Brown et al., 1983; Hill et al., 1983; Vasyliunas, 1983], understanding the physics of the Io torus within Jupiter's magnetosphere is a major objective of the planetary community and JIMO will be able to measure the precipitation of this plasma into Jupiter's upper atmosphere and the transport, cooling and energization of this plasma as it moves to the outer magnetosphere. JIMO with our neutral imager will be able to observe the high latitude boundary of the plasma within Jupiter's inner radiation belts and its expected Io signature.

For the three icy Galilean moons, a major scientific objective is to describe the spatial and temporal distributions of the products of radiolysis and sputtering of icy surfaces [Johnson and Sittler,1990; Johnson et al., 1998; Johnson et al 2003a]. Because of the dominance of water ice, the principal products (e.g., $H_2O$, $H_2$ and $O_2$), their dissociation products, and their ions will determine the nature of the ionosphere and will affect the atmosphere-magnetosphere interaction. An oxygen corona has been detected at Europa and Ganymede [Hall et al., 1995, 1998] produced by radiolysis by the energetic charged particle bombardment on these surfaces. Radiolysis also produces hydrogen peroxide [Carlson et al., 1999a; Moore and Hudson, 2000] and oxygen trapped in the icy surfaces [Spencer et al., 1995; Calvin et al., 1996; Calvin and Spencer, 1997]. $CO_2$ is seen to be present in the ice on all three icy satellites [Carlson, 1999; McCord et al., 1998a,b] with a $CO_2$ atmosphere (and likely CO) observed on Callisto [Carlson 1999]. Therefore, radiolysis of the $CO_2$

in ice can produce carbonic acid on any of the icy satellites [Moore et al., 1991; Johnson et al., 2003a] or the $CO_2$ could be a dissociation product of a higher organic [Johnson et al., 2003a]. An ozone-like feature has been detected on Ganymede [Noll et al., 1996] and sulfuric acid has been suggested to be present on Europa [Carlson et al., 1999b]. Atmospheric sodium and potassium have been seen as sputtering products [Johnson, 2000, 2002; Leblanc et al., 2002]. In addition, Iogenic sulfur implanted into the icy surfaces may have been seen on all of the icy satellites [Lane et al. 1981; Nelson et al. 1987; Noll et al., 1995; 1997].

Organics and related molecules may have been detected on the surfaces of Callisto and Ganymede [McCord et al., 1997; Johnson et al. 2003a]. McCord et al. [1998a, 1999] reported $MgSO_4$ and $Na_2SO_4$ salt hydrates on the surface of Europa, although an alternative interpretation of the same near-infrared spectrometer data suggests $H_2SO_4$ acid hydrate instead [Carlson et al., 1999b, 2002]. Key to resolution of this dispute is the measurement of the elemental ratios S/O, Mg/O, and Na/O, preferably for neutrals emitted directly from concentrations of non-ice material on Europa. Europa appears to be a net source of Na for the Jovian magnetosphere [Johnson, 2000; Johnson et al., 2002; Leblanc et al., 2002], possibly from a subsurface ocean. Non-ice constituents have also been detected on Ganymede and Callisto [McCord et al., 1998b] and presumably arise from some yet-unknown combinations of external and internal sources. Furthermore, the observed sodium and potassium could have had an ocean source at Europa [Leblanc et al., 2002].

Neutral and ionic composition originating from the moon surfaces, and accessible to LEJINA, may then include O, S, Mg, and Na, which are particularly of interest in relation to origins of the moons and potential subsurface oceans [Kargel et al., 2000]. For astrobiology the biogenic elements C, N, O, P, and S [Pierazzo and Chyba, 2002] are also essential components of living organisms and might be associated with remnants of biological samples ejected to the highly irradiated [Cooper et al., 2001] moon surfaces from subsurface oceans. All of these must be considered against a background of solar-abundance materials, including these and other species in recognizable ratios, delivered to the moon surfaces over billions of years by cometary impacts [Pierazzo and Chyba, 2002]. Isotopes of the light elements (H, He, C, N, O) might also be accessible to LEJINA measurements, given sufficient mass resolution for an enhanced design, and would be of interest for (1) tracing the origin of magnetospheric species, since sputtering fractionates escaping neutrals in favor of light isotopes [Johnson, 1990; Johnson et al., 2003a], and for (2) setting limits on abundances of materials from biological sources, which also favor light isotopes. Since sputtering preferentially leaves heavier isotopes on the moon surfaces on long time scales, LEJINA imaging of light isotope concentrations, e.g. in disrupted regions on Europa's surface, could mark a spot for future landed science to search for freshly emergent oceanic and perhaps even biological materials.

The bombardment of the various moons of Jupiter can produce the sputtered ejection of energetic neutrals, which can form coronal atmospheres around these bodies and neutrals within Jupiter's magnetosphere [Johnson, 1990; Johnson et al., 2002]. There are extensive laboratory data on the sputtering of neutrals from icy surfaces bombarded by energetic ions, for which 100-1000 neutrals can be ejected for every ion incident on the satellite surface. Our proposed Hi-Cap instrument will have the ability to detect the pickup ions (atomic and molecular) from these neutral clouds [Bar-Nun et al., 1985; Johnson, 1990; Johnson, 1998; Baragiola et al., 2003; Johnson et al., 2003b]. JIMO with its orbit extending out to Callisto would be able to image and detect *in situ* the hot plasma of ionized neutral clouds and remotely the neutral clouds themselves of the above mentioned species. As a neutral mass spectrometer we can measure the principal atmospheric constituents at 100 km. We will make measurements of those neutrals, which become negatively or positively charged, down to 1 eV. This will allow us to be able to directly detect the high energy tails of the sputtered neutrals so that trace sputtered species may be directly detected. Noting their energy and direction, these can then be traced to rough locations on the surface because the collision probability with the background atmosphere is small. Using model energy spectra and our Monte Carlo calculations of the sputtered atmospheres, quantitative information can then be obtained on the surface abundance of detected species.

Since, the global properties of the magnetic field surrounding the moons (i.e., Europa or Ganymede) will affect the spatial and pitch angle distributions of the ions interacting with the neutral clouds surrounding these bodies, the neutral imaging capability of our instrument will allow us to determine the global properties of the induced or internal magnetic fields of these bodies when combined with both *in situ* plasma and magnetic field measurements. This in turn, will allow us to infer, in the case of Europa, the presence of a global ocean under its icy crust.

*Therefore, there exists the potential for detecting a wide range of* ***exogenic and endogenic*** *molecules within Jupiter's magnetosphere and both neutral imaging and ion measurements of atomic and molecular species are desirable for the JIMO mission.*

### iii. Technical Challenges for Jovian Low Energy Neutral Atom Imaging

Although low energy neutral atom imaging is now a proven space flight technology, certain technical challenges exist for the application of this technique to the Jovian environment.

(1) Because oxygen and sulfur are major components of the Jovian magnetosphere, a viable neutral atom imager must have the capability to resolve these species and others in the Jovian environment.

(2) The intense radiation environment will require triple coincidence measurements to keep background accidental events as low as possible. The Galileo Interim Radiation Electron (GIRE) model of Garrett et al. [2003], the earlier Divine and Garrett [1983] trapped radiation model for Jupiter, and published electron and ion spectra from Galileo Orbiter data of Cooper et al. [2001] provide the basis for our evaluation of radiation effects on LEJINA and the need for less vulnerable operational modes.

(3) The long duration of the trip to Jupiter and the mission itself will require on-board capability to purge and replenish the conversion surfaces.

(4) Unlike low energy neutral atom imaging on the IMAGE mission in which the nominal target was outflow from the polar caps, the Jovian processes of interest range from sputtering off of moon surfaces to neutrals generated in the Io torus to neutrals associated with the Jovian polar regions. The wide spectrum of potential Jovian targets will require a much larger field-of-view than was sufficient at Earth.

### iv. Science Objectives and Research Focus Areas from Solar System Exploration Roadmap

The ESS, Exploration of the Solar System, science theme "seeks to understand all aspects of our Solar System, including the planets, satellites, small bodies, and Solar System materials, and the search for possible habitats of life beyond Earth."

The proposed study covers the Mission Statement "To Explore the Universe and Search for Life" with the Strategic Goal "Explore the Solar System and the Universe beyond, understand the origin and evolution of life, and search for evidence of life elsewhere" and addresses two Science Objectives under the Solar System Exploration OSS Theme.

It addresses the Science Objective "Learn how the Solar System originated and evolved to its current state" through Research Focus Area (b) "Study the processes that determine the characteristics of bodies in our solar system and how these processes operate and interact" because the proposed instrument will determine how and what material is sputtered from icy satellites and how this material is processed afterwards by the Jovian system. In addition, it will address science topic (d) "Learn what our Solar System can tell us about extra-solar planetary systems" because Jupiter-like planets have been found around other stars and many of the same processes at work in the Jovian system will also be relevant in these extra-solar planetary environments.

The proposed instrument also addresses the Science Objective "Determine the characteristics of the Solar System that led to the origin of life" through the Research Focus Area "Determine the nature, history, and distribution of volatile and organic compounds in the solar system" because the time-of-flight system will be able to resolve molecular species. Additionally, it will address the Research Focus Area "Identify the habitable zones in the Solar System" because it may contribute to confirming the Galileo results indicating subsurface oceans may exist on Europa and Callisto.

## Instrument Heritage

### i. IMAGE/LENA

The Low Energy Neutral Atom (LENA) imager on the IMAGE spacecraft [Burch, 2000; Moore et al., 2000] was succesfully launched and became operational during 2000. This instrument is designed specifically to look at the neutral atoms that form when low energy (~10's of eV) ions which frequently flow upward from the polar regions of the terrestrial ionosphere charge exchange with atoms which comprise Earth's exosphere. This outflow is well-correlated with changes in the solar wind ram pressure [Moore et al., 1999]. Figure 1 shows one image of ionospheric outflow from the LENA instrument during a period when there was a strong correlation between the outflow and the solar wind ram pressure on June 24, 2000 [Fuselier et al., 2001; Khan et al., 2003]. In this figure, a wire-frame Earth can be seen behind the outflow, in green. The bars at the left and right indicate the solar wind ram pressure and outflow flux, respectively. The entire outflow movie may be viewed at http://lena.gsfc.nasa.gov/.

In addition to ion outflow, LENA has observed other neutral atom signals, as well. Figure 3 shows two LENA images from June 8, 2000. In these two images, the Earth may be seen at zero degrees polar and zero degrees azimuth along with dipole field lines (L=3 and 6.6) drawn to aid interpretation. The signal near 180 degrees polar angle is where LENA's look direction is closest to the direction of the Sun. Each image is averaged over an hour and taken while IMAGE was near apogee, about 8 $R_E$. The left side shows the neutral atom

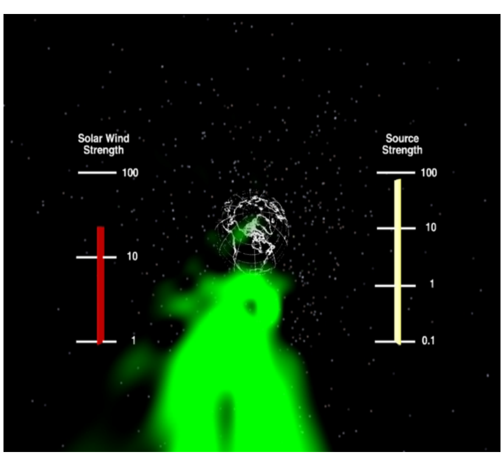


Figure 2. IMAGE/LENA observations of low energy (10's of eV) ion outflow from the Earth's auroral region.

observations before a coronal mass ejection (CME) hit the Earth and the right side after the CME hit the Earth [Moore et al., 2001; Collier et al., 2001]. The region surrounding the Earth in the lower part of the image brightens considerably following passage of the CME, which is expected because terrestrial neutral atom emission increases during periods of strong geomagnetic activity. Note, however, that the Sun signal which appears in the upper half of the image and was originally thought to be due to solar UV also brightens after the passage of the CME. An examination of solar UV data showed that there was no increase in solar UV at this time to explain the enhancement observed in the Sun pulse following the CME. Subsequent analysis showed that this brightening is due to the presence of neutral atoms in the solar wind formed when solar wind protons charge exchange with neutral gas in the interplanetary medium. These observations marked the first detection of the neutral solar wind.

### ii. Expected Jovian Count Rates

The IMAGE/LENA instrument relies on low energy neutral atoms converting to negative ions after near-specular reflection off a conversion surface at a small incident angle (15 degrees). Once ionized, the incident neutrals are accelerated, pass through an electrostatic analyzer, then enter a time-of-flight/position sensing unit. Studies of the conversion properties of bare tungsten in support of LENA showed that about 1% of the incident neutrals became negative ions after interacting with the conversion surface. By employing a cesiated tungsten surface, we expect a yield of at least 10%. If about 10% of the converted neutrals pass through the toroidal deflection system and a time-of-flight subsystem efficiency is likewise of the order of 10%, our estimated LEJINA efficiency is ~$10^{-3}$.

Figure 4 shows modelled Europa $O_2$ and $H_2O$ sputter source 100 km upward flux spectra. The "non-sticky" (not chemically reactive at the surface) $O_2$ is thermalized by repeated contacts with the 100K surface and consequently has less flux above 1 eV than the water. The $H_2O$, however, sticks so the 100 km flux has the same shape as the source flux. The 100 km spectra for other sticky species including Na and Mg resemble that for $H_2O$. A comparison of the $H_2O$ source and the 100 km spectra shows that such species can be imaged from source sputtering sites and therefore constrain composition at those sites for geologic correlations [Shematovich et al., 2003].

The $H_2O$ flux at the energies of interest for LEJINA (>1 eV) is comparable to about $10^4$/cm$^2$/s/eV and the $O_2$ flux is about $10^3$/cm$^2$/s/eV. Depending on the energy passband used, LEJINA will observe an $H_2O$ flux of ~$10^5$/cm$^2$/s and an $O_2$ flux of ~$10^4$/cm$^2$/s. Using these fluxes and the estimated efficiency above and taking the effective instrument aperture size of ~5 cm$^2$, we expect a signal of the order of $10^3$ $H_2O$ counts/s and $10^2$ $O_2$ counts/s at an altitude of 100 km above Europa.

Interesting species such as Na, which we know is present from Na D emission observed from Earth, and Mg, which is expected but for which there is not yet a direct measurement, will be present at around 0.1% to 1% of the level of $H_2O$. Consequently, sufficient statistics for these species could be accumulated over a few minutes of LEJINA observation time. K is also present, but with a lower limit Na/K abundance of 25 for K from Europa (since some of it is likely from Io). LEJINA will also be able to image K with sufficient statistics over maybe tens of minutes of observing time.

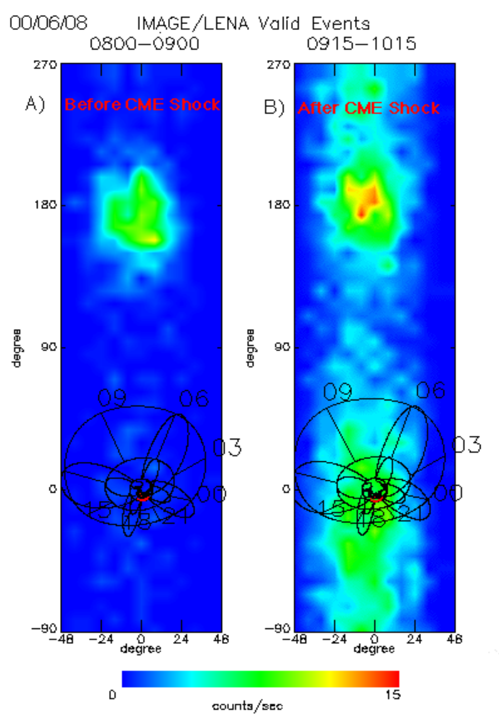


Figure 3. IMAGE/LENA observations of ~4 keV neutral solar wind before and after the arrival of a coronal mass ejection at Earth. Also visible in the lower half of the figure are enhanced neutral atom emissions from the magnetosphere.

## PROPOSED ACTIVITIES

### i. Approach

To develop an instrument designed specifically to image low energy neutral atoms in the Jovian environment, we will exploit our experience with conversion surface and heater technology from the LENA instrument launched on the Imager for Magnetopause to Aurora Global Exploration (IMAGE) spacecraft on March 25, 2000 while incorporating a time-of-flight/position sensing system based on some aspects of the CASSINI/CAPS experiment [Young et al., 1998]. Additionally, this instrument proposal will be partially leveraged by an already-funded SECID instrument development effort (P.I. E. Sittler) which will extend the capability of CAPS.

The proposed LEJINA instrument is shown conceptually in Figure 5. A 360 degree field-of-view is achieved using a “top hat” style geometry as opposed to the wedge geometry of LENA in which particles enter a 90 degree field-of-view. This 360 degree field-of-view will be divided into thirty-two 11.3 degree pixels.

Neutral atoms (or ions, depending on the sensor voltages, as discussed later) enter the instrument through a 12.5 degree polar angle colli-

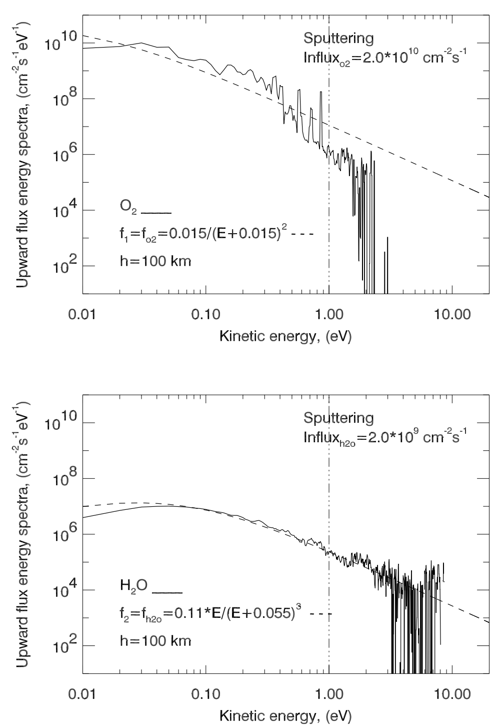


Figure 4. Modelled Europa $O_2$ (top) and $H_2O$ (bottom) sputter source 100 km upward flux spectra.

mator/charged particle rejecter. In the case of neutral atoms converted to negative ions, they are steered by a deflector element into a toroidal deflection system, which selects the ions based on the original neutral's energy. This is in contrast to the method used by LENA in which neutral energy is inferred based on separation induced by the post-acceleration followed by position sensing. We anticipate that this method will result in a cleaner neutral energy spectrum.

Once exiting the toroidal deflection system, the negative ions are post-accelerated through 15 kV and enter a time-of-flight/position sensing unit based on the CAPS/SECID design. The azimuthal angle, that is the angle around the 360 degree field-of-view, is determined by position sensing of secondary electrons on the outside of the top microchannel plate stack. A solid anode behind the position sensing anode may be used to generate a quick signal as a start pulse for the time-of-flight measurement.

The ions then travel ballistically through an effectively field-free region where they encounter another MCP stack with a thin (possibly 2 $\mu g/cm^2$) carbon foil assembly placed about 5 mm above the MCP surface. A signal drawn from a solid (i.e. non-position sensing) anode on the back of the stack produces the stop signal. Additionally, secondary electrons produced off the top of the foil as the ions penetrate are guided up to the top MCP stack where they produce another stop signal resulting in a triple-coincidence measurement.

Because one concern about the Jovian environment is the intense radiation, particularly around Europa, it may be reasonable to entertain the notion of have a quadruple coincidence mode for periods of very high background due to penetrating radiation. This "Europa-mode" could be effected by drawing secondary electrons off the side of the top foil closest to the toroidal deflection system to trigger additional MCPs around the housing of the instrument.

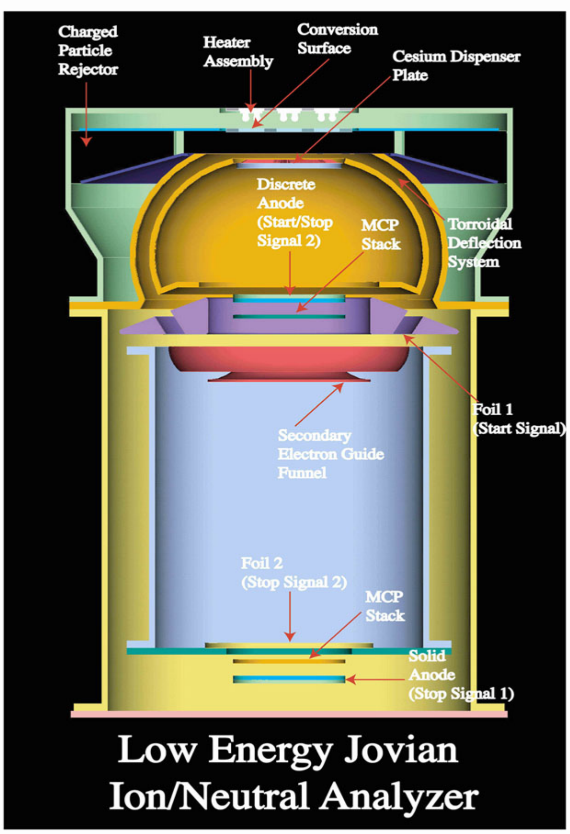


Figure 5. Schematic diagram of the LEJINA instrument concept.

## ii. Methodology

There are four major subsystems which compose the proposed LEJINA instrument: (a) the charged particle rejector/collimator, (b) the heater/conversion surface, (c) the electrostatic optics and (d) the time-of-flight/position sensing unit.

The proposed study will, in the first year, specifically address optimizing each of the individual subsystems separately with simulations and testing designed specifically and appropriately for the subsystem.

The second year of the study will incorporate the various subsystems into integrated tests. As part of the second year activities, since it will require the mating of the heater assembly to the optics assembly, tests will be performed to evaluate how frequently and to what degree cesium will need to be deposited onto the conversion surface in-flight. Potential methods of coping with the harsh Jovian radiation environment (outside of the triple coincidence measurements) will also be examined during year two.

The third year of the study will integrate the entire instrument into a functioning laboratory prototype. This will involve laboratory electronics rather than flight-qualified power supplies, but the tests will be close enough to the actual flight unit that there will be no question of flight qualifiability. In addition, other issues will be addressed such as substituting other surfaces for the tungsten, such as chemical vapor deposited (CVD) diamond, which would not have a serious impact on instrument design. Among other issues to be addressed in the third year are additional heat dissipation strategies.

**a. Charged Particle Rejector/Collimator**

Charged particle rejectors are a common feature of all neutral atom imaging instruments, or at least instruments designed specifically for neutral atom imaging. The LEJINA design will be similar to that employed successfully on LENA. However, the LEJINA design, as shown in Figure 5, will cover an entire 360 degree view, rather than 90 degrees, with about a 12.5 degree opening angle.

The LENA collimator successfully rejects charged particles with energy per charges up to about eight times the applied voltage using a four plate alternating voltage design. It is anticipated that the LEJINA collimator can be designed to be at least as effective as the LENA collimator with only two plates. However, this will be investigated and, depending on the results, more plates may be added or the linear dimension may be increased to achieve this goal.

**b. Heater/Conversion Surface**

Although low energy neutral atom imaging works effectively with untreated tungsten surfaces, in part due to sputtering from the surface, the most effective method is to treat the tungsten surfaces periodically with low work function cesium which facilitates direct neutral atom conversion to negative ions. Over time the conversion efficiency will be reduced, resulting in lower instrument efficiency. Part of the final heater/conversion surface subassembly will be the ability to monitor the work function of the surface. This is accomplished by illuminating the surface with blue diodes and measuring the photoelectric current.

However, such an approach requires purging the surface before application of the cesium. Work done in support of the LENA instrument indicated that the tungsten surfaces would need to be heated to about 800 Celcius (cherry red) for effective purging. Although heaters and cesium dispensers were not part of the LENA instrument as flown, some development was done in this regard. Figure 6 shows a prototype LENA heater assembly. Heating was effected by running about 100 Watts of power through a filament sandwiched between alumina wafers.

Figure 7 shows the temperature of the tungsten, as measured by a thermocouple attached to the surface, as a function of time. With this design, it takes about eight or so minutes to reach 800 Celcius, after which there will be some time devoted to cooling off the surface. Clearly, in an instrument requiring high voltage, the high voltage must be shut down prior to heater operation and a reasonable amount of time must pass before the high voltages could be ramped back up. The entire sequence may take a few hours. This means that it would be most efficient in terms of scientific yield to operate all heaters simultaneously, This will require close to a kilowatt of power. Following surface cleansing and cool-down, the cesium dispensers will be activated for about two minutes. Each dispenser requires several Watts of power.

The heaters will fit together to span the entire area covered by the facets by using seven hexagonal heaters.

Heat dissipation issues will be addressed by creating a thermal model of the instrument.

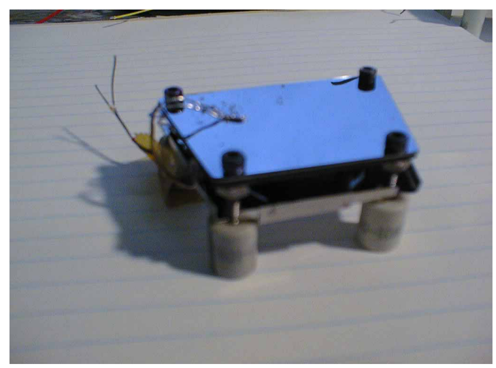

Figure 6. Prototype LENA tungsten conversion surface/heater assembly.

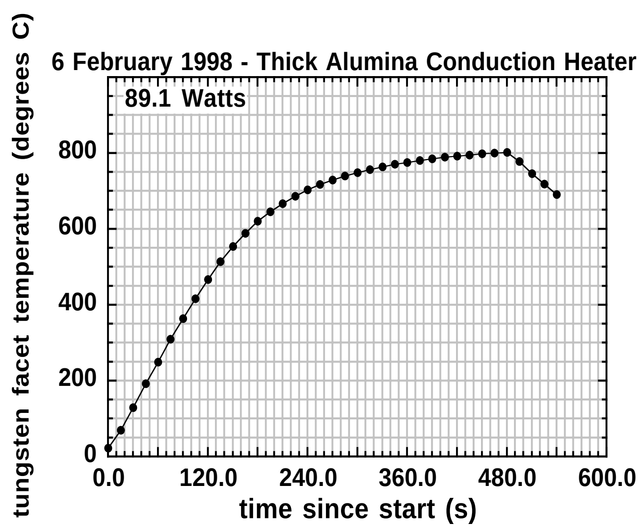


Figure 7. Temperature profile for the above prototype LENA heater assembly.

However, since the surface looks out into space, it is not anticipated that this will be a major problem.

**c. Electrostatic Optics**

Converted ions are guided by the steering deflector element into a toroidal energy per charge selector as illustrated in Figure 8. This approach is quite different from that employed by LENA. Using this method, we will have both higher energy resolution, since that is determined by the toroidal analyzer and not degraded by spatial scattering off the conversion surface, and the inherent ability to separate the very low energy sputtered component from the directly converted neutrals. Because neutral atoms will only capture a single electron in an interaction with the conversion surface, there will not be the usual charge state ambiguity that accompanies the application of energy per charge analyzers to ion measurements (although there will be that ambiguity in ion mode, as discussed below).

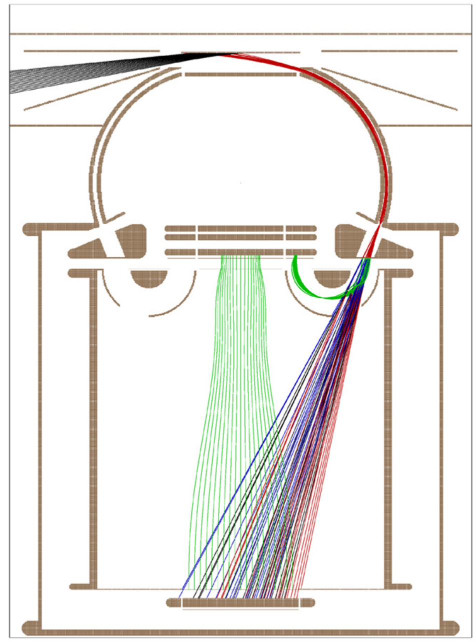

Figure 8. Sample trajectories of 70 eV neutrals through the LEJINA instrument. With the charged particle deflectors off this instrument would also detect Jovian ions.

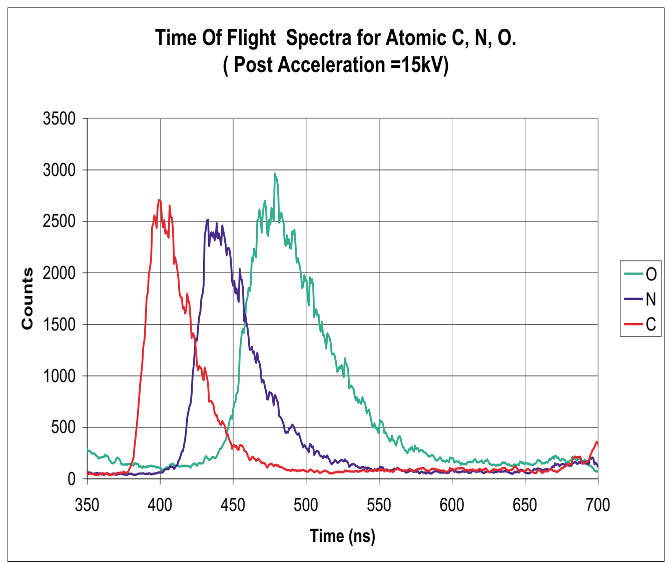


Figure 9. MCP time-of-flight distributions for carbon, nitrogen and oxygen from a standard time-of-flight unit, in this case from the Cassini/CAPS instrument.

**d. TOF/Position Sensing Subsystem**

The time-of-flight unit will determine the angle around the 360 degree aperture the neutral or ion entered based on position sensing of the secondary electrons emitted by the top foil immediately following post-acceleration. To reduce the complexity of the design for this application, we intend to use discrete anodes, each with its own preamplifier. This is the preferred approach for two reasons. First, a fast pulse for time-of-flight determination can be drawn directly off the 12.3 degree discrete anode rather than requiring a separate solid anode if a wedge or strip position sensing method were applied. Second, giving each of the anodes its own preamplifier is a more robust system to the potential failure of preamplifiers in the harsh Jovian environment than a wedge or strip method which would have less redundancy.

Two major constituents of the Jovian magnetospheric system are Iogenic oxygen and sulfur. Thus, it is essential that, at the very least, the time-of-flight unit be able to resolve these species.

Figure 9 shows pulse height spectra obtained at GSFC from the CAPS Ion Mass Spectrometer operating in medium resolution mode, which has dimensions similar to that proposed for LEJINA. These data show that even carbon, nitrogen and oxygen are resolved, so that resolving oxygen from sulfur will not be a technical challenge.

**e. Molecule Observations**

One of the major scientific questions involving Europa is whether the “salts” observed in near-infrared observations [McCord et al., 1998a, 1999, 2001], mainly on the trailing hemisphere, are some combination of $Na_2SO_4$, $MgSO_4$ or else are really $H_2SO_4$ [Carlson et al., 1999b] acid hydrate. Thus, in addition to looking at Europa surface and atmospheric abundance of S, O, Na, Mg and K, a major science goal is the detection and characterization of molecules and molecular fragments.

Molecules are successfully converted to negative (or positive) ions at the conversion surface, will be steered into the toroidal deflection system. After exiting the carbon foil at the time-of-flight unit, the molecule will have dissociated into its constituent parts.

LEJINA will have three different methods to determine that a neutral molecule rather than a neutral atom entered the tof unit.

First, heavy atoms that are part of a molecule will dissociate with a speed equal to that of entire molecule post-accelerated to 15 keV rather than that of the atom itself accelerated to 15 keV so that molecular constituents will be moving slower through the tof unit than the neutral atoms. SRIM (The Stopping and Range of Ions in Matter) simulations indicate that this difference will be large enough to be seen in the tof unit. For example, water accelerated to 15 kV which dissociates in the carbon foil will produce an oxygen with 13.3 keV. The time-of-flight profiles for oxygen at 15 kV (red trace) as compared to 13.3 kV (blue trace) are shown in Figure 10 and will be resolvable.

Second, the constituent parts of molecules entering the tof unit will, of course, generate a start signal simultaneously. For molecular constituents that are close in mass such as carbon and oxygen, the stop signals will be effectively simultaneous since the constituent particles will travel through the drift region at the same speed [e.g. Nordholt et al., 1998]. However, for molecular constituents that have a large mass difference, such as oxygen and hydrogen, the stop signals will be closely spaced, but not simultaneous. This is because the constituent atoms having different masses will lose differing amounts of energy in the carbon foil. Thus, if the electronics detects one start signal corresponding to two closely-spaced stop signals, it will indicate a molecule.

The blue and green traces in Fig. 10 show SRIM simulations of the tof spectra of 13.3 keV oxygen and 0.83 keV hydrogen, the energies associated with water exiting the foil. The two have different mean tofs and different tof distribution shapes. The sum of the two is shown with the purple trace and represents the observed tof distribution which would allow the two constituent peaks to be inferred and the molecule type established. This would require some modeling.

Third, additional information on the molecule will be obtained by pulse-height differences that result when two different species impinge on an MCP, as illustrated by the GSFC data shown in Figure 11, and as has been successfully flown on the IMAGE/HENA instrument [Mitchell et al., 2000]. To accomplish this, a second foil would be placed about 5 mm above the stop MCP to effect the differences in the pulse height distributions shown in Fig. 11. This would also be a statistical measurement of the molecular composition and require some modeling to extract the separate distributions from the combined spectra.

By exploiting all three of these approaches, LEJINA will be able to determine the composition of and image the molecular environment of the Jovian icy moons.

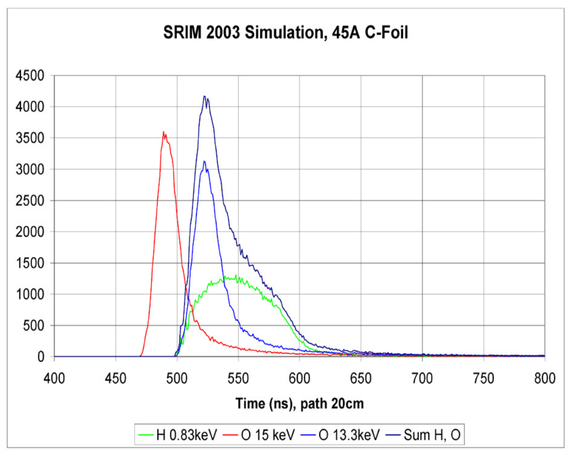


Figure 10. Time-of-flight spectra simulated with SRIM.

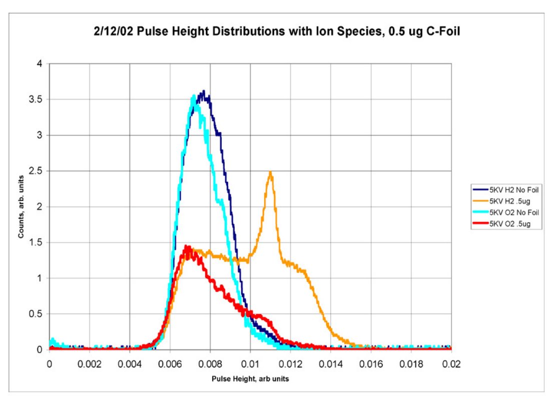


Figure 11. MCP pulse height distributions for hydrogen and oxygen. Note that the introduction of a foil, even the thinnest foil tested, significantly changes the pulse height distribution generated by hydrogen and oxygen although the two distributions are very similar in the case of no foil.

### iii. Ion/Neutral Atom Sensor

The instrument design allows operation in an ion or neutral atom mode (neutral atoms converted to positive ions) by changing potentials in the ESA and time-of-flight sections, and in the case of the ion mode suitably biasing the surface as well as disabling the collimator/charged particle rejector. The collimator, however, may be used at low voltage to guide the ions into the toroidal deflection system. This establishes the particle's energy per charge. The positive ions then enter the time-of-flight unit, after being accelerated through a negative potential of 15 kV, where a mass measurement is made.

In addition to providing a measurement of the local Jovian plasma environment, this mode will aid interpretation of the neutral atom data by allowing an evaluation of the degree of energetic particle contamination, that is, whether or not energetic charged particles are getting past the collimator and contaminating the neutral atom measurements. This is especially important in the Jovian environment where ions are quite energetic [Collier and Hamilton, 1995].

The scientific advantage in including an additional sensor outfitted for ions and neutral atoms converted to positive ions is that it not only provides a measure of the local Jovian plasma environment, but also allows imaging of many more neutral species that would not be observed if one were limited only to those forming negative ions. For example, Na is expected to form positive ions after interacting with the conversion surface.

### iv. High Voltage Issues

For the neutral atom to negative ion conversion sensor, the tof MCPs and associated electronics will be floating at a negative potential. Therefore, the data from the unit will need to be optically coupled to ground. For the ion and neutral atom to positive ion sensor, this will not be an issue because the top MCP will be at negative potential and the anode will be at ground potential. The optocoupling electronics and their associated power supplies are part of the ongoing SECID development at GSFC. However, if not available within our time frame, we plan to capacitively couple the signals to ground.

### v. Technical Readiness Level Discussion

Low energy neutral atom imaging, down to about 10 eV using conversion surface technology became a proven spaceflight technique following the launch of the IMAGE mission in March of 2000 [Burch, 2000]. However, as previously mentioned, the Jovian environment presents certain challenges which will require considerable modifications to the LENA instrument on IMAGE which was designed for the terrestrial environment.

Thus, the LENA instrument in this context may be considered a "representative model or prototype" which has been tested in a "relevant" environment, namely, space. This test was, of course, successful in the case of the LENA instrument, and therefore this technology is assessed at Technical Readiness Level (TRL) 6.

## CONCLUSION

Low energy neutral atom imaging must be a part of any mission to Jupiter's moons which seeks to determine their makeup, history and even their potential for sustaining life. The LEJINA instrument directly addresses all three of the top-level JIMO science goals: (1) scout the potential for sustaining life (by contributing to the issue of subsurface oceans and surface chemicals), (2) investigate the origin and evolution of these moons (through sputtering studies), and (3) determine radiation environments and the rates of weathering by material (through neutral atom imaging).

### i. Science Objectives and Instrument Capabilities

The science objectives of the proposed instrument involve determining the composition of Jovian satellites using sputtered material as well as addressing issues of Jovian system dynamics. This requires low energy neutral atom imaging, from a few keV down to as low as possible, preferably at least a couple eV.

### ii. Quality and Uniqueness of Science Enabled by Expanded Capabilities

Low energy neutral atom imaging with conversion surface technology is a proven spaceflight technique. However, a lengthy mission through a harsh radiation environment such as Jupiter's requires the capability to periodically purge and resurface with cesium the conversion surfaces. This requires heater elements which will consume large amounts of power not readily available on standard missions but easily within the capability of nuclear electric power and propulsion technology.

**Most of the neutrals in the Jovian system of interest in addressing the science questions of the Jupiter Icy Moons Orbiter fall in the low energy range, below a couple keV. It will be essential to have a viable low energy neutral atom imager on this mission.**

## PLAN OF WORK

### I. Year One

(i) Completed by Dennis Chornay and Edward Sittler: Ray tracing simulations of instrument optics will be performed to maximize throughput. This includes optimization of collimator design to achieve charged particle rejection to as high energies as possible. SRIM code will be used to characterize the expected response in the tof section for various species.

(ii) Completed by Paul Rozmarynowski: Based on results of ray tracing and SRIM simulations, a refined set of concept and mechanical drawings will be produced for the toroidal deflection system.

(iii) Completed by Dennis Chornay, Michael R. Collier and Paul Rozmarynowski: Laboratory work based on previous experience with LENA heaters will be continued to produce a viable heater design. This design will then be incorporated into the mechanical drawings with special emphasis on optimizing cooling time and maintaining reasonable temperatures at critical components.

(iv) Completed by John Cooper and Robert E. Johnson: Simulation of Jovian plasma environments relevant to the JIMO mission with emphasis on processes, such as sputtering, that produce neutral atoms in the LEJINA energy range.

(v) Completed by Michael Coplan: Testing of surfaces with respect to their conversion efficiency for not only H and O but also expanded to other atoms such as S and C as well as stable molecules and free radical molecules.

### II. Year Two

(i) Completed by John Cooper, Robert E. Johnson, Dennis Chornay and Michael Coplan: Evaluate the effects of the expected radiation environment on the instrument to determine degree of required shielding and other designs that will mitigate radiation effects.

(ii) Completed by Dennis Chornay and Michael R. Collier: Integrate heater units into instrument containing conversion surfaces and optics to test with a neutral beam using a Quantar.

(iii) Completed by Dennis Chornay, Michael R. Collier, Michael A. Coplan and Paul Rozmarynowski: Design and test a suitable tof/position sensing unit for LEJINA based on the CAPS/SECID design. The anode board will be supplied by the University of Maryland.

(iv) Completed by John Cooper and Robert E. Johnson: Based on efficiency estimates and decay times supplied by Michael R. Collier and Dennis Chornay, simulations developed in year one will be used to estimate the LEJINA response in various regions of the Jovian environment. These results will be used to optimize instrument design parameters and develop simulated LEJINA images.

### III. Year Three

(i) Completed by Paul Rozmarynowski: Design based on results of tests on tof/position sensing unit in the second year, a tof/position sensing unit to mate to integrated instrument.

(ii) Completed by Paul Rozmarynowski, Dennis Chornay, Michael Coplan and Michael R. Collier: Using ray tracing, design suitable collimator to mate to instrument.

(iii) Completed by Michael A. Coplan: An examination of a number of new surfaces including those derived from low work-function alloys, intercalated materials, and surfaces upon which a variety of self-assembled monolayers will be deposited.

(iv) Completed by John Cooper and Robert E. Johnson: Based on their models customized for this application and the established instrument design, evaluate LEJINA response to the Jovian environment at various times in the JIMO mission. Both neutrals and plasma effects will be considered.

(v) Completed by Michael R. Collier, Dennis Chornay and Edward Sittler: Final testing of completely integrated LEJINA instrument.

## MANAGEMENT STRUCTURE

**Michael R. Collier** as Principal Investigator will be responsible for the overall management and success of the proposal. He will be involved either directly or in a oversight role with every aspect and facet of the proposal work.

Each one of the Co-Investigators in this proposal will have the specific roles listed below:

**Edward Sittler**

Edward Sittler is a Co-Investigator on the Cassini/CAPS experiment and Principal Investigator on a funded Sun-Earth Connections Instrument Development proposal. The instrument design proposed herein is in-part based on designs in each of these instruments, particularly the time-of-flight/position sensing unit. Thus, Dr. Sittler will play a major role in defining and testing the instrument and its subsystems especially those with CAPS and SECID heritage.

**Dennis Chornay**

Dennis Chornay will be responsible for the optimization of the preliminary design by performing ray tracing and other appropriate simulations and investigating heat dissipation issues. In addition, Dr. Chornay during the second year of the proposal tenure, if granted, will do a detailed study of the preliminary instrument design as established during the first year of the proposal and based on the expected radiation environment will determine whether or not quadruple coincidence mode will be necessary and feasible for some parts of the mission.

**Robert E. Johnson**

Robert Johnson is an expert in the areas of modeling the effect of the Jovian radiation environment on icy satellites, modeling and calculating charge exchange cross sections, and monte carol modeling of the atmospheres and neutral tori that compose the Jovian system. He will work closely with the hardware development team to assure that the instrument specifications are consistent with maximizing the scientific yield.

**John F. Cooper**

John Cooper is a leading researcher studying the Jovian radiation environment and its impact on and interaction with the Jovian moons. He will work closely with Robert E. Johnson on the modeling efforts and their application to LEJINA instrument design. Radiation environment models for JIMO, such as the GIRE model of Garrett et al. [2003], will be utilized to guide the LEJINA team in selection of radiation-hardened parts and in development of background elimination schemes for LEJINA. He will also examine potential areas of synergy between neutral atom imaging and radio plasma imaging which may part of the JIMO instrument suite.

**Michael Coplan**

Michael Coplan is an expert in surface chemistry and will provide support and guidance on issues relating to the tungsten (as well as other) conversion surfaces and cesiation. He will aid in evaluation and mitigation of radiation effects including issues dealing with the sensitivity of electronics to noise generated by the Jovian environment. In addition, he will provide guidance on general questions of neutral chemistry and other various hardware-related issues.

## TASK CALENDAR

Year

05 a. Optimize sensor optics
   (i) Perform ray tracing simulations of sensor geometry to optimize geometrical factor by increasing the spacing $\Delta r$ between the hemispherical deflection plates.
   (ii) Optimize entrance geometry by selecting appropriate scattering angles and charged particle deflection plate geometries.
b. Sensor development
   (i) Design and fabricate toroidal deflection system to mate with conversion surface assembly.
   (ii) Test conversion surface/hemispherical deflection system subsystem in lab.
c. Heater development
   (i) Develop a viable heater designed capable of taking initially 30C tungsten facets of an appropriate size up to 800 C within a few minutes reliably and repeatedly.
   (ii) Establish design parameters for optimum cesium dispensing.
d. Model development - Refinement of current models with emphasis on processes that produce neutral atoms in the LEJINA energy range.

06 a. Perform radiation study on preliminary instrument design to determine whether or not a quadruple coincidence mode would be feasible and appropriate. Examine other approaches to shielding and other techniques to mitigate radiation effects.
b. Integrate developed heater units into instrument containing both conversion surface and optics assemblies.
c. Design and test suitable time-of-flight/position sensing unit for instrument based on Cassini/CAPS and SECID heritage. Lab electronics will be used to validate techniques discussed to detect molecules.
d. Use results of models to optimize instrument design for making those measurements which will have the greatest impact on resolving current science questions. Develop simulated images of LEJINA response.

07 a. Integrate time-of-flight unit and test the fully integrated unit.
b. Investigate other potential surfaces for conversion such as CVD diamond and additional heat dissipation strategies.
c. Design preliminary flight electronics capable of resolving molecules.
d. Complete modeling work by incorporating measured LEJINA instrument characteristics.

## CLEARLY MEASURABLE MILESTONES

Year

05

1. Heater Performance - Using laboratory power supplies, thermocouples and other supplies under vacuum conditions, demonstrate a heater design compatible with the LEJINA instrument that is capable of heating its tungsten surfaces up to 800 C repeatedly.
2. Freeze Optimum Geometry - Reach closure through simulations of the optimum geometry for the optics.
3. Mechanical Drawings - Produce a preliminary set of mechanical drawings defining interfaces between subsystems. This is necessary since subsystem development will be done in parallel.
4. Fabricate and test the toroidal deflection systems and the conversion surface assembly both individually and as an integrated system.
5. Establish based on modelling effort and anticipated instrument capabilities which specific science questions will be answered by what LEJINA observations.

06

1. Efficiency Degradation - Perform tests on integrated conversion surface/heater and optics assemblies under good vacuum conditions with an ultraviolet source to evaluate the conversion surface degradation with time and how frequently the surface will have to be re-cesiated in the Jovian environment.
2. Radiation Study - Reach a conclusion about whether or not a quadruple coincidence mode will be useful in the Jovian environment given the JIMO mission. Determine shielding and electronics requirements necessary to operate effectively in the Jovian environment.
3. Test Instrument in Flight-Like Mode - Test the integrated instrument by taking it through a complete cycle of measurement, cleansing, cesiation and measurement, as it will be doing in-flight
4. Test tof/position sensing unit - Verify through laboratory testing using a Quantar that the time-of-flight/ position sensing unit functions as expected and can resolve different atoms such as carbon from oxygen from sulfur.
5. Develop simulated images of LEJINA observations in the Jovian plasma environment.

07

1. Successfully test fully integrated instrument in environment and manner to as closely as possible represent that expected on the JIMO mission.
2. Surface Selection - Select optimal conversion surface type for Jovian application (e.g. tungsten, CVD diamond, etc.)
3. Complete preliminary design of flight electronics capable of resolving molecules in the Jovian system.
4. Publish instrument paper and modeling results.

## REFERENCES


Bar-Nun, A., G. Herman and Yu Melker, Ejection of $H_2O$, $O_2$, $H_2$ and H from water ice by 0.5-6 keV $H^+$ and $Ne^+$ ion bombardment, Surface Science, 150, 143, 1985.

Baragiola, R.A., R. Vidal, W. Svendsen, J. Schou, M. Shi, D. Bahr and C.L. Atteberry, Sputtering of water ice, Nucl. Instr. And Methods in Phys. Res., in press, 2003.

Belcher, J.W., The low-energy plasma in the Jovian magnetosphere, Physics of the Jovian Magnetosphere, A.J. Dessler (Ed.), Cambridge University Press, 68, 1983.

Brown, R.A., C.B. Pilcher and D.F. Strobel, Spectrophotometric studies of the Io torus, Physics of the Jovian Magnetosphere, A.J. Dessler (Ed.), Cambridge University Press, 197, 1983.

Burch, J.L., IMAGE Mission overview, Space Sci. Rev., 91, 15,1-14, 2000.

Calvin W.M. and J.R. Spencer, Latitudinal distribution of O2 on Ganymede: Observations with the Hubble Space Telescope, 130 (2), 505-516, 1997.

Calvin, W.M., R.E. Johnson, and J.R. Spencer, O2 on Ganymede: Spectral characteristics and plasma formation mechanisms, Geophys. Res. Lett, 23(6), 673-676, 1996.

Carlson, R.W., A tenuous carbon dioxide atmosphere on Jupiter's moon Callisto, Science, 283, 820, 1999.

Carlson, R.W., Anderson, M.S., Johnson, R.E. et al., Hydrogen peroxide on the surface of Europa, Science, 283 (5410), 2062-2064, 1999a.

Carlson, R.W., R.E. Johnson and M.S. Anderson, Sulfuric acid on Europa and the radiolytic sulfur cycle, Science, 286 (5437), 97-99, 1999b.

Carlson, R. W., M. S. Anderson, R. E. Johnson, M. B. Schulman, and A. H. Yavrouian, Sulfuric acid production at Europa: The radiolysis of sulfur in water ice, Icarus, 157, 456-463, 2002.

Carr, M. H., et al., Evidence for a subsurface ocean on Europa, Nature, 391, 363-365, 1998.

Collier, Michael R. and D.C. Hamilton, The relationship between kappa and temperature in energetic ion spectra at Jupiter, Geophys. Res. Lett., 22, 303-306, 1995.

Collier, Michael R., Thomas E. Moore, Keith W. Ogilvie, Dennis Chornay, J.W. Keller, S. Boardsen, James Burch, B. El Marji, M.-C. Fok, S.A. Fuselier, A.G. Ghielmetti, B.L. Giles, D.C. Hamilton, B.L. Peko, J.M. Quinn, E.C. Roelof, T.M. Stephen, G.R. Wilson, and P. Wurz, Observations of neutral atoms from the solar wind, J. Geophys. Res., 106, 24,893-24,906, 2001.

Cooper, J.F., R.E. Johnson, B.H. Mauk, H.B. Garrett and N. Gehrels, Energetic ion and electron irradiation of the icy Galilean satellites, Icarus, 149, 133, 2001.

Cravens, T.E., E. Howell, J.H. Waite Jr. and G.R. Gladstone, Auroral oxygen precipitation at Jupiter, J. Geophys. Res., 100, 17153, 1995.

Divine, N, and H. B. Garrett, Charge particle distributions in Jupiter's magnetosphere, J. Geophys. Res., 88, 6889-6903, 1983.

Drossart, P., B. Bezard, S.K. Atreya, J. Bishop, J.H. Waite Jr. and D. Boice, Thermal profiles in the Auroral regions of Jupiter, J. Geophys. Res., 98, 18803, 1993.

Fok, M.-C., T.E. Moore, M.R. Collier and T. Tanaka, Neutral atom imaging of solar wind interaction with the Earth and Venus, J. Geophys. Res., submitted, 2003.

Fuselier, S. A., Ghielmetti, A. G., Moore, T. E., Collier, M. R. et al., Ion outflow observed by IMAGE: Implications for source regions and heating mechanisms, Geophys. Res. Lett., Vol. 28 , No. 6 , 1163-1166, 2001.

Garrett, H. B., et al., Galileo Interim Radiation Electron Model, JPL Publication 03-006, 2003.

Report and software available from http://www.openchannelfoundation.org/projects/GIRE.

Hall, D.T., D.F. Strobel, P.D. Feldman, M.A. McGrath, and H.A. Weaver, Detection of an oxygen atmosphere on Jupiter's moon Europa. Nature, 373, 677-679, 1995.

Hall, D.T., P.D. Feldman, M.A. McGrath, and D.F. Strobel, The far-ultraviolet oxygen airglow of Europa and Ganymede, Astrophys. J., 499, 475-481,1998.

Hill, T.W., A.J. Dessler and C.K. Goertz, Magnetospheric Models, Physics of the Jovian Magnetosphere, A.J. Dessler (Ed.), Cambridge University Press, 353, 1983.

Johnson, R.E., Energetic charged-particle interactions with atmospheres and surfaces, Springer-Verlag, Berlin, 1990.

Johnson, R.E., Sputtering and desorption form icy surfaces, In: B. Schmitt, C. deBergh (Eds.), Solar System Ices, Kluwer, Netherlands, 303, 1998.

Johnson, R.E., Sodium at Europa, Icarus,143, 429, 2000.

Johnson, R.E. and E.C. Sittler, Sputter-produced plasma as a measure of satellite surface composition: Cassini Mission, Geophys. Res. Lett., 17, 1629-1632, 1990.

Johnson, R.E., R.M. Killen, J.H. Waite, and W.S. Lewis, Europa's surface and sputter-produced ionosphere, Geophys. Res. Lett., 25, 3257-3260, 1998.

Johnson, R.E., F. Leblanc, B.V. Yakshinskiy and T.E. Madel, Energy distributions for desorption of sodium and potassium from ice: The Na/K ratio at Europa, Icarus, 156, 136-142, 2002.

Johnson, R.E., R.W. Carlson, J.F. Cooper, C. Paranicus, M.H. Moore and M. Wong, Radiation effects on the surfaces of the Galilean satellites, In Jupiter: Satellites, Atmosphere and Magnetosphere, Ed. F. Bagenal, in press, 2003a.

Johnson, R.E., T.I. Quickenden, P.D. Cooper, A.J. McKinley and C. Freeman, The production of oxidants in Europa's surface, Astrobio J., submitted, 2003b.

Kane, M., A convected kappa distribution model for hot ions in the outer Jovian magnetosphere, Ph.D. Dissertation, The Johns Hopkins University, Baltimore, MD, 142 pp., 1991.

Kargel, J.S., J. Kaye, J.W.I. Head, G. Marion, R. Sassen, J. Crowley, O. Prieto, and D. Hogenboom, Europa's crust and ocean: Origin, composition, and prospects for life, Icarus 94, 368-390, 2000.

Khan, H., M.R. Collier and T.E. Moore, Case study of solar wind pressure variations and neutral atom emissions observed by IMAGE/LENA, J. Geophys. Res., in press, 2003.

Khurana, K.K., M.G. Kivelson, D.J. Stevenson, G. Schubert, C.T. Russell, R.J. Walker and C. Polanskey, Induced magnetic field as evidence for subsurface oceans in Europa and Callisto, Nature, 395 (6704), 777-780, 1998.

Kivelson, M. G., K. K. Khurana, C. T. Russell, R. J. Walker, J. Warnecke, F. V. Coroniti, C. Polanskey, D. J. Southwood, and G. Schubert, Discovery of Ganymede's magnetic field by the Galileo spacecraft, Nature, 384, 537-541, 1996.

Kivelson, M. G., K. K. Khurana, F. V. Coroniti, S. Joy, C. T. Russell, R. J. Walker, J. Warnecke, L. Bennett, and C. Polanskey, The magnetic field and magnetosphere of Ganymede, Geophys. Res. Lett., 24(17), 2155-2158, 1997.

Kivelson, M. G., K. K. Khurana, D. J. Stevenson, L. Bennett, S. Joy, C. T. Russell, R. J. Walker, C. Zimmer, and C. Polanskey, Europa and Callisto: induced or intrinsic fields in a periodically varying plasma environment, J. Geophys. Res., 104, 4609-4625, 1999.

Kivelson, M. G., K. K. Khurana, C. T. Russell, M. Volwerk, R. J. Walker, and C. Zimmer, Galileo magnetometer measurements: A stronger case for a subsurface ocean at Europa, Science, 289, 1340-1343, 2000.

Kivelson, M. G., K. K., Khurana, and M. Volwerk, The Permanent and Inductive Magnetic Moments of Ganymede, Icarus, 157, 507-522, 2002.

Krimigis, S.M. and E.C. Roelof, Low-energy particle population, Physics of the Jovian Magnetosphere, A.J. Dessler (Ed.), Cambridge University Press, 106, 1983.

Lane, A.L., R.M. Nelson, and D. L. Matson, Evidence for sulphur implantation in Europa's UV absorption band, Nature, 292, 38-39, 1981.

Leblanc, F., R.E. Johnson and M.E. Brown, Europa's sodium atmosphere: An ocean source?", Icarus, 159, 132-144, 2002.

McCord, T.B., et al., Organics and other molecules in the surfaces of Ganymede and Callisto, Science, 278, 271, 1997.

McCord, T.B., et al., Salts on Europa's surface detected by Galileo's Near Infrared Mapping Spectrometer, Science, 280, 1242, 1998a.

McCord, T.B., et al., Non-water ice constituents in the surface material of the icy Galilean satellites from the Galileo near-infrared mapping spectrometer investigation, J. Geophys. Res., 103, 8603, 1998b.

McCord, T.B., et al., Hydrated salt minerals on Europa's surface from the Galileo near-infrared mapping spectrometer (NIMS) investigation, J. Geophys. Res., 104, 11827, 1999.

McCord, T. B., T. M. Orlando, G. Teeter, G. B. Hansen, M. T. Sieger, N. G. Petrik, and L. Van Keulen, Thermal and radiation stability of the hydrated salt minerals epsomite, mirabilite, and natron under Europa environmental conditions, J. Geophys. Res., 106, 3311-3319, 2001.

McNutt, R.L., J.W. Belcher, J.D. Sullivan, F. Bagenal and H.S. Bridge, Departure from rigid corotation of plasma in Jupiter's dayside magnetosphere, Nature, 280, 803, 1979.

Metzger, A.E., D.A. Gilman, J.L. Luthey, K.C. Hurley, H.W. Schnopper, F.D. Seward, J.D. Sullivan, The detection of X rays from Jupiter, J. Geophys. Res., 88, 7731, 1983.

Mitchell, D.G., A.F. Cheng, S.M. Krimigis, E.P. Keath, S.E. Jaskulek, B.H. Mauk, R.W. McEntire, E.C. Roelof, D.J. Williams, K.C. Hsieh, and V.A. Drake, INCA - The Ion-Neutral Camera for Energetic Neutral Atom Imaging of the Saturnian Magnetosphere, Opt. Eng., 32 (12), 3096-3101, 1993.

Mitchell, D.G., S.E. Jaskulek, C.E. Schlemm et al., High Energy Neutral Atom (HENA) Imager for the IMAGE mission, Space Sci. Rev., 91, 67-112, 2000.

Moore, M.H. and R.L. Hudson, IR detection of $H_2O_2$ at 80 K in ion-irradiated laboratory ices relevant to Europa, Icarus, 145, 282, 2000.

Moore, M.H., R. Khanna and B. Donn, Studies of proton irradiated $H_2O+CO_2$ and $H_2O+CO$ ices and analysis of synthesized molecules, J. Geophys. Res., 96, 17541, 1991.

Moore, T.E., W.K. Peterson, C.T. Russell, M.O. Chandler, M.R. Collier, H.L. Collin, P.D. Craven, R. Fitzenreiter, B.L. Giles, and C.J. Pollock, Ionospheric mass ejection in response to a CME, Geophys. Res. Lett., 26(15), 2339-2342, 1999.

Moore, T.E., D.J. Chornay, M.R. Collier, F.A. Herrero, J. Johnson, M.A. Johnson, J.W. Keller, J.F. Laudadio, J.F. Lobell, K.W. Ogilvie, P. Rozmarynowski, S.A. Fuselier, A.G. Ghielmetti, E. Hertzberg, D.C. Hamilton, R. Lundgren, P. Wilson, P. Walpole, T.M. Stephen, B.L. Peko, B. Van Zyl, P. Wurz, J.M. Quinn and G.R. Wilson, The Low-Energy Neutral Atom Imager for IMAGE, Space Sci. Rev., 91, 155-195, 2000.

Moore, T. E. , Collier, M. R., Burch, J. L., Chornay, D. J. et al., Low Energy Neutral Atoms in the Magnetosphere, Geophys. Res. Lett. Vol. 28 , No. 6 , p. 1143, 2001.

Nelson, R, A.L. Lane, D.J. Matson, G.J. Veeder, B.J. Buratti, and E.F. Tedesco, Spectral Geometric Albedos of the Galilean Satellites from 0.24 to 0.34 Micrometers: Observations with the International Ultraviolet Explorer, Icarus, 72, 358, 1987.

Noll, K.S., H.A. Weaver, and A.M. Gonella, The albedo spectrum of Europa from 2200Å to 3300Å, J. Geophys. Res., 100, 19057-19059, 1995.

Noll, K.S., R.E. Johnson, A.L. Lane, D.L. Domingue and H.L. Weaver, Detection of ozone on Ganymede, Science, 273, 341, 1996.

Noll, K.S., R.E. Johnson, M.A. McGrath, and J.J. Caldwell, Detection of $SO_2$ on Callisto with the Hubble Space Telescope, Geophys. Res. Lett., 24, 1139, 1997.

Nordholt, J.E., J.-J. Berthelier, D.M. Burr et al., The Cassini Ion Mass Spectrometer: Performance Metrics and Techniques, in Measurement Techniques in Space Plasmas: Particles, R.F. Pfaff, J.E. Borovsky and D.T. Young eds., Geophysical Monograph 102, American Geophysical Union, pp. 209-214, 1998.

Pappalardo, R. T., et al., Does Europa have a subsurface ocean? Evaluation of the geological evidence, J. Geophys. Res., 104(E10), 24015-24055, 1999.

Pierazzo, E., and C. F. Chyba, Cometary delivery of biogenic elements to Europa, Icarus, 157, 120-127, 2002.

Seiff, A., D.B. Kirk, T.C.D. Knight, J.D. Mihalov, R.C. Blanchard, R.E. Young, G. Schubert, U. von Zahn, G. Lehmacher, F.S. Milos and J. Wang, Structure of the atmosphere of Jupiter: Galileo Probe Measurements, Science, 272, 844, 1996.

Shematovich, V. I., and R. E. Johnson, Near-surface oxygen atmosphere at Europa, Adv. Sp. Res., 27, 1881-1888, 2001.

Shematovich, V. I., R. E. Johnson, and J. F. Cooper, Surface-bounded atmosphere of Europa, to be submitted to Icarus, 2003.

Sommeria, J., L.B. Jaffel and R. Prange, On the existence of supersonic jets in the upper atmosphere of Jupiter, Icarus, 119, 2, 1995.

Spencer, J.R., W.M. Calvin and M.J. Person, Charged-coupled device spectra of the Galilean satellites:Molecular oxygen on Ganymede, J. Geophys. Res., 100, 19049, 1995.

Vasyliunas, V.M., Plasma distribution and flow, Physics of the Jovian magnetosphere, A.J. Dessler (Ed.), 395, 1983.

Waite, J.H. Jr., T.E. Cravens, J. Kozyra, A.F. Nagy, S.K. Atreya and R.H. Chen, Electron precipitation and related aeronomy of the Jovian thermosphere and ionosphere, J. Geophys. Res., 88, 6143, 1983.

Waite, J.H., F. Bagenal, F. Seward, C. Na, G.R. Gladstone, T.E. Cravens, K.C. Hurley, J.T. Clarke, R. Elsner and S.A. Stern, ROSAT observations of the Jupiter aurora, J. Geophys. Res., 99, 14799, 1994.

Waite, J.H. Jr., et al., in Rontgenstrahlung from the Universe, Proceedings of the International Conference on X-ray Astronomy and Astrophysics (MPE Report 263), Wurzburg, Germany, 25 to 29 September 1995, H.U. Zimmermann et al., Eds. Max Planck Institute fur Extraterrestrische Physik, Garching, Germany, 641, 1996.

Waite, J.H. Jr., G.R. Gladstone, W.S. Lewis, P. Drossart, T.E. Cravens, A.N. Maurellis, B.H. Mauk and S. Miller, Equatorial X-ray emissions: Implications for Jupiter's high exospheric temperatures, Science, 276, 104, 1997.

Young, D.T., B.L. Barraclough, JJ. Berthelier et al., Cassini Plasma Spectrometer Investigation, in Measurement Techniques in Space Plasmas: Particles, R.F. Pfaff, J.E. Borovsky and D.T. Young eds., Geophysical Monograph 102, American Geophysical Union, pp. 237-242, 1998.

Zimmer, C., K.K. Khurana and M.G. Kivelson, Subsurface oceans on Europa and Callisto: Constraints from Galileo magnetometer observations, Icarus, 147(2), 329-347, 2000.

## FACILITIES AND EQUIPMENT

The work proposed herein will be performed primarily using existing facilities available in the Laboratory for Extraterrestrial Physics (LEP) at the Goddard Space Flight Center. No new computer purchases are required.

Laboratory facilities at Goddard include two 36 inch diameter vacuum systems capable of accelerating electrons and ions to energies from as low as ten Volts to about 20 keV. In many cases, for example, the hemispherical deflection system and the time-of-flight unit, testing may be effected with ion beams. In cases in which the testing must be performed with neutrals, the beam will be created from the accelerated ion beam by leaking gas into the chamber near the filament. The remaining charged component of the beam will be stripped out using biased grids at the end of the beam tube. Alternatively, thin carbon foils may be used prior to the grids, depending on the beam energy, to effect a neutral component.

## COST PLAN

A cost plan for the tenure of this proposal is provided at the end of this document. As indicated, the Principal Investigator, Co-Investigator Edward Sittler, and Technical Support person Paul Rozmarynowski are civil servants and do not require salary funding other than the G&A Assessment, although salaries for the Civil Servants have been fully costed. The proposal covers a fraction of Dr. Cooper's time. Separate budgets are attached corresponding to the appropriate line items in the GSFC budget for the University of Virginia and the University of Maryland detailing costs associated with Robert E. Johnson, Dennis Chornay and Michael A. Coplan's contributions to this proposal. Paul Rozmarynowski is partially funded for support activities. A modest amount ($4.3K) is included in the third year of the budget for costs associated with publishing the results of the study. $2K per year is listed for travel to at least one major meeting to report to the community on the progress of the instrument development effort and to get feedback from the community.

The budget for the University of Virginia lists Valery Shematovitch, Francois Leblanc and Mau Wong who have performed Europa modelling and may be assisting with the modelling efforts there but are not listed as Co-Is or Collaborators on this proposal because they do not fit into the definitions of these roles as laid out in the "Guidebook for Proposers Responding to an NRA."

All money from this proposal will be spent in the United States by United States institutions.

## PERSONNEL

Michael R. Collier

Biographical Summary

Michael R. Collier currently serves as a civil servant in the Interplanetary Physics Branch of the NASA/Goddard Space Flight Center where he has been for about five years. Here he contributed to fabricating, calibrating, commanding and analyzing data from the Low Energy Neutral Atom (LENA) imager on the IMAGE spacecraft. He studies primarily low energy neutral atoms in the Earth's vicinity.

He received his doctorate in Space Physics from the University of Maryland, College Park in 1993 where he wrote his dissertation on Energetic Particle Acceleration in the Jovian Magnetosphere. While at the University of Maryland, he analyzed Voyager 1 and 2 LECP energetic particle data both in the interplanetary medium and in the magnetospheres of the outer planets. In addition, he studied Voyager 1 and 2 magnetometer data in and in the proximity of Jupiter's magnetosphere. He was also involved with hardware projects, performing numerical simulations to determine the design characteristics and dimensions of a solar wind composition instrument later launched on the WIND spacecraft (MASS) and testing instrument prototypes. After the launch of the WIND spacecraft in late 1994, he ground commanded the MASS, SWICS and STICS instrument package and analyzed data from the three sensors, particularly the MASS instrument, to determine abundance ratios, temperatures, and distribution functions of minor ion species in the solar wind. Dr. Collier moved to Goddard Space Flight Center in late 1996 where he has analyzed IMP 8, WIND and Geotail magnetometer and particle data to study the effects of pressure discontinuities on the terrestrial magnetotail, to characterize interplanetary magnetic field correlations and absolute agreement and to examine the properties of magnetic clouds, particularly shocks internal to magnetic clouds.

He is the author or coauthor of over 30 peer-reviewed scientific articles dealing with, among other topics, heliospheric, terrestrial magnetospheric and outer planets magnetospheric physics.

Selected Publications


Collier, Michael R., Dennis J. Chornay, John W. Keller, Michael Coplan, Norman J. Dionne, Brahim El Marji, Federico Herrero, Joe Hirman, Jeffrey Houser, John Moore and James A. Slavin, Tomographic imaging of electron distributions: Leveraging computing power advances to produce inexpensive, low-power, lightweight, and robust instrumentation, Rev. Sci. Instr., 74, 1002-1007, 2003.

Collier, Michael R., T.E. Moore, K.W. Ogilvie, D. Chornay, J.W. Keller, S. Boardsen, J. Burch, B. El Marji, M.-C. Fok, S.A. Fuselier, A.G. Ghielmetti, B.L. Giles, D.C. Hamilton, B.L. Peko, J.M. Quinn, E.C. Roelof, T.M. Stephen, G.R. Wilson, and P. Wurz, Observations of neutral atoms from the solar wind, *J. Geophys. Res.*,106, 24,893-24,906, 2001.

Collier, Michael R., A. Szabo, W. Farrell, J.A. Slavin, R.P. Lepping, R. Fitzenreiter, B. Thompson, D.C. Hamilton, G. Gloeckler, G.C. Ho, P. Bochsler, D. Larson, and L. Ofman, Reconnection remnants in the magnetic cloud of October 18-19, 1995: A shock, monochromatic wave, heat flux dropout, and energetic ion beam, *J. Geophys. Res.*, 106,15,985-16,000, 2001.

Collier, Michael R., Adam Szabo, James A. Slavin, R.P. Lepping and S. Kokubun, IMF length scales and predictability: The two length scale medium, *Int. J. Geomag. Aeron.*, 2, 3-16, 2000.

Collier, Michael R., Evolution of kappa distributions under velocity space diffusion: A model for the observed relationship between their spectral parameters, *J. Geophys. Res.*, 104, 28,559-28,564, 1999.

Collier, M.R., J.A. Slavin, R.P. Lepping, K. Ogilvie, A. Szabo, H. Laakso and S. Taguchi, Multispacecraft observations of sudden impulses in the magnetotail caused by solar wind pressure discontinuities: WIND and IMP 8, *J. Geophys. Res.*, 103, 17,293-17,305, 1998.

Collier, Michael R., J.A. Slavin, R.P. Lepping, A. Szabo and K. Ogilvie, Timing accuracy for the simple planar propagation of magnetic field structures in the solar wind, *Geophys. Res. Lett.*, 25, 2509-2512, 1998.

Collier, Michael R., D.C. Hamilton, G. Gloeckler, G. Ho, P. Bochsler, R. Bodmer and R. Sheldon, The oxygen-16 to oxygen-18 abundance ratio in the solar wind observed by WIND/MASS, *J. Geophys. Res*., 103, 7-13, 1998.

Collier, Michael R., D.C. Hamilton, G. Gloeckler, G. Ho, P. Bochsler and R.B. Sheldon, Neon-20, oxygen-16, and helium-4 densities, temperatures, and suprathermal tails in the solar wind determined with WIND/MASS, *Geophys. Res. Lett.*, 23, 1191-1194, 1996.

Collier, M.R. and R.P. Lepping, Jovian magnetopause breathing, *Planet. Space Sci.*, 44, 187-197, 1996.

Collier, Michael R., The adiabatic transport of superthermal distributions modelled by kappa functions, *Geophys. Res. Lett.*, 22, 2673-2676, 1995.

Collier, Michael R. and D.C. Hamilton, The relationship between kappa and temperature in energetic ion spectra at Jupiter, *Geophys. Res. Lett.*, 22, 303-306, 1995.

Collier, Michael R., On generating kappa-like distribution functions using velocity space Levy flights, *Geophys. Res. Lett.*, 20, 1531-1534, 1993.

Edward Sittler

Biographical Summary

Dr. Ed Sittler has been a staff scientist of the Laboratory for Extraterrestrial Physics (LEP) since 1980. He received his B.S. degree in Physics at Hofstra University in 1972 where he graduated Magna Cum Laude with honors in Physics. He received his Ph.D. in Physics at MIT in 1978. He has contributed substantially to the understanding and observation of interplanetary and magnetospheric plasmas, both through instrument development and the interpretation of the data. His association with Voyager 1 and 2 plasma instruments as a Co-Investigator has resulted in many papers detailing the electron environments, bow shocks, magnetotails, and other properties of the outer planets as well as a polytrope law for electrons in the solar wind. He has either led or contributed to publications on the Io torus, the Titan interaction, the magnetospheric interaction with Triton and the magnetospheres of Jupiter, Saturn, Uranus and Neptune. He was the first one to show that there is a hot magnetospheric wind blowing down the distant tail of Jupiter using Voyager 2 observations. As Cassini Co-Investigator he has provided key subsystems to the Cassini Plasma Spectrometer (CAPS) Experiment and is now in the process of developing a comprehensive Monte Carlo simulation code for CAPS and the SECID 3D ion mass spectrometer instrument being developed at Goddard for which he is the PI. He is also leading the calibration of the CAPS IMS prototype at Goddard.

Selected Publications

Sittler, E.C., Jr., R. E. Johnson, J. D. Richardson, S. Jurac, M. McGrath and D. Young, Pickup Ions at Dione and Enceladus: Cassini Plasma Simulations, J. Geophys. Res., in press, 2003.

Blanc, et al., Magnetospheric and Plasma Science with Cassini-Huygens, section on Icy Satellite Interactions by E. C. Sittler Jr. and R. Johnson, Space Science Reviews, in review, 2003.

Sittler, E. C., Jr., and R.E. Hartle, Triton's ionospheric source: Electron precipitation or photoionization, J. Geophys. Res., 101, 10,863, 1996.

Sittler, E.C., Jr., Real-time spectral analysis algorithm for space plasma three-dimensional ion mass spectrometers, Reviews of Scientific Instruments, 64, 2771, 1993.

Johnson, R.E. and E.C. Sittler Jr., Sputter-produced plasma as a measure of satellite surface composition: The Cassini Mission, Geophys. Res. Lett., 17, 1629, 1990.

Johnson, R.E., M.K. Pospieszalska, E.C. Sittler Jr., A.F. Cheng, L.J. Lanzerotti and E.M. Sieveka, The neutral cloud and heavy ion inner torus at Saturn, Icarus, 77, 311, 1989.

Sittler, E.C., Jr., and D.F. Strobel, Io plasma torus electrons: Voyager 1, J. Geophys. Res., 92, 5741, 1987.

Sittler, E.C., Jr., R.P. Lepping, B.H. Mauk and S.M. Krimigis, Detection of a hot plasma component within the core regions of Jupiter's distant magnetotail, J. Geophys. Res., 92, 9943, 1987.

Sittler, E.C., Jr., K.W. Ogilvie and R. Selesnick, Survey of electrons in the Uranian magnetosphere: Voyager 2 observations, J. Geophys. Res., 92, 15,263, 1987.

Scudder, J.D., E.C. Sittler Jr., and H.S. Bridge, A survey of the plasma environment of Jupiter: A view from Voyager, J. Geophys. Res., 86, 8157, 1981.

## Dennis Chornay

### Biographical Summary

Dr. Chornay, received his B.Sc. in Physics in 1978 and completed his Ph.D. in Atomic Physics in 1982, both at the University of Manchester. The subject of his thesis was the experimental determination of lifetimes of excited states via the emission of UV photons, using electron-photon coincidence techniques. From 1982 to 1984 he was a Research Associate in the Institute for Physical Science and Technology, at the University of Maryland, where he performed electron impact ionization experiments to obtain data on single electron momentum densities in a number of atoms and molecules.

From 1985 to the present Dr. Chornay has been a Research Associate with the Astronomy program at UMD, engaged in research and instrument development at Goddard Space Flight Center. During this time he was responsible for many aspects of the design, implementation and calibration of a number of particle instruments, including the Solar Wind Experiment on WIND and the HYDRA experiment on the POLAR spacecraft. He was a co-investigator on two proposals for instrument development related to a solar probe mission. In one case, a solution to the nadir-viewing problem was developed using a secondary heat shield in conjunction with a periscope fabricated from electrostatic grid mirrors. In the second case a novel time of flight spectrometer that employs a gating technique was designed and tested. This is suitable for use in high flux regions, and has a number of advantages over the carbon foil method.

He contributed extensively in the design and development of the Low Energy Neutral Atom imager on the IMAGE spacecraft, and in the design and calibration of a tophat electron spectrometer, which is a part of the PlasMag instrument on the Triana mission. Currently, he is a co-investigator on the SECID 3D ion mass spectrometer instrument under development at Goddard, and is also involved in the calibration work of the Ion Mass Spectrometer prototype for the Cassini mission.

While at GSFC, Dr. Chornay has also been responsible for the design and construction of a versatile ion and electron beam calibration facility. This may be used in a fully automated manner to test various instrument operating modes, and to verify design concepts.

### Selected Publications


Vaisberg, O., B. Goldstein, D. Chornay, J. Keller et al., Ultra Fast Plasma Analyzer – an All-Sky Camera for Charged Particles. Proceedings of "Solar Encounter: The first Solar Orbiter Workshop" (ESA SP-493), Sept 2001.

Moore, T.E., D. Chornay, M.R. Collier, et al., The Low Energy Neutral Atom imager for the IMAGE mission, Space Sci. Rev., 91, 155-195, 2000

Keller, John W., Dennis J. Chornay, Floyd H. Hunsaker, Keith W. Ogilvie, M. A Coplan, A Gated Time-of-Flight Tophat Plasma Composition Analyzer for Space Physics Research, Rev. Sci. Inst., 70, 3167, 1999.

Smith,M.F., D. J. Chornay, J. W. Keller et al., Imaging Low-Energy (<1keV) Neutral Atoms: Ion-Optical Design, Measurment Techniques in Space Plasmas - Fields, Geophysical Monograph 103, American Geophysical Union, Washington DC, p.263, 1998.

Chornay, Dennis J. Floyd H. Hunsaker and John W. Keller, Evaluation of an Elliptical Grid Mirror Electrostatic Analyzer for Space Applications, Rev. Sci. Instrum. 68, 1604, March 1997.

Sittler Jr.,E.C., D. Chornay, J. Keller, K. W. Ogilvie, and A. Roberts, Observational requirements for in situ plasma instrumentation for solar probe, Proc. Scientific Basis for Robotic Exploration Close to the Sun, Marlboro, Massachusetts, April 15-18, 1996.

Ogilvie, K.W., D. J. Chornay,R.J. Fitzenreiter et al. , SWE, A Comprehensive Plasma Instrument for the Wind Spacecraft, Space Science Rev., 71(1-4), 55-77, 1995.

## John F. Cooper

### Biographical Summary

Dr. John F. Cooper is currently a scientist with the Raytheon Technical Services Company at Goddard Space Flight Center serving as a Space Science Data Operations (SSDOO) project Principal Scientist. He received his B.S. in physics from the Georgia Institute of Technology in 1972 and his M.S. and Ph.D. from the University of Chicago in 1978 and 1983, respectively. From 1983 through 1985, Dr. Cooper worked as a Postdoctoral Research Fellow at the Max Planck Institute for Extraterrestrial Physics, moving then to the California Institute of Technology. After three years there, he moved to Louisiana State University as a Senior Research Associate, where he stayed until 1990, when he joined GSFC.

Dr. Cooper's research interests include Galileo Orbiter Heavy Ion Counter data analysis for magnetospheric ion interactions with Io and Europa and Galileo Orbiter Energetic Particle Detector data modeling for Galilean moon surface irradiation effects. He has performed numerical modeling of energetic ion and electron motions in magnetic environments of Galilean moons, of Europa's atmosphere and radiation-induced surface chemistry, of irradiation effects on Kuiper Belt Objects from heliospheric plasma and cosmic ray ions and of energetic electron transport and moon interactions in the magnetosphere of Saturn.

Dr. Cooper is the lead author on the AAS/DPS-sponsored decadal report on science and mission priorities for Europa exploration as well as for Kuiper Belt Objects. He is also a member of the Science Definition Team for the Jupiter Icy Moons Orbiter (JIMO) mission and a Co-Organizer of AGU sessions on space weathering (Fall 2002) and JIMO magnetospheric science (Fall 2003).

### Selected Publications


Cooper, J. F., E. R. Christian, J. D. Richardson, and C. Wang, Proton irradiation of Centaur, Kuiper Belt, and Oort Cloud objects at plasma to cosmic ray energy, Earth Moon and Planets, in press, 2003.

Cooper, J. F., C. B. Phillips, J. R. Green, X. Wu, R. W. Carlson, L. K. Tamppari, R. J. Terrile, R. E. Johnson, J. H. Eraker, and N. C. Makris, Europa exploration: Science and mission priorities, in The Future of Solar System Exploration, 2003 - 2013, Community Contributions to the NRC Solar System Exploration Decadal Survey, ASP Conf. Ser. 272, M. Sykes (ed.), pp. 217-252, Astron. Soc. Pac., San Francisco, CA, 2002.

Cooper, J. F., R. E. Johnson, B. H. Mauk, H. B. Garrett, and N. Gehrels, Energetic ion and electron irradiation of the icy Galilean satellites, Icarus, 49, 133-159, 2001.

Cooper, J. F., E. C. Sittler, Jr., S. Maurice, B. Mauk, and R. S. Selesnick, Local time asymmetry of drift shells for energetic electrons in the middle magnetosphere of Saturn, Adv. Sp. Res., 21(11), 1479 -1482, 1998.

Maurice, S., E. C. Sittler, Jr., J. F. Cooper, B. H. Mauk, M. Blanc, and R. S. Selesnick, Comprehensive analysis of electron observations at Saturn: Voyager 1 and 2, J. Geophys. Res., 101, 15211-15232, 1996.

Cooper, J. F., and E. C. Stone, Electron signatures of satellite sweeping in the magnetosphere of Uranus, J. Geophys. Res., 96(A5), 7803-7821, 1991.

Cooper, J. F., Satellite sweeping of electrons at Neptune and Uranus, GRL, 17, 1665-1668, 1990.

Stone, E. C., J. F. Cooper, A. C. Cummings, F. B. McDonald, J. H. Trainor, N. Lal, R. E. McGuire, and D. L. Chenette, Energetic particles in the Uranian magnetosphere, Science, 233, 93-97, 1986.

Cooper, J. F., J. H. Eraker, and J. A. Simpson, The secondary radiation under Saturn's A-B-C rings produced by cosmic ray interactions, J. Geophys. Res., 90, 3415-3427, 1985.

Cooper, J. F., Nuclear cascades in Saturn's rings: cosmic ray albedo neutron decay and the origins of trapped protons in the inner magnetosphere, J. Geophys. Res., 88, 3945-3954, 1983. (Ph.D. Thesis).

## Michael A. Coplan

### Biographical Summary

Dr. Michael A. Coplan is a member of the Institute for Physical Science and Technology at the University of Maryland where he is the Director of the Chemical Physics Program. He received his B.A. in Chemistry in 1960 from Williams College and his M.S. and Ph.D. from Yale University in Physical Chemistry in 1961 and 1963 respectively.

From 1963-1965, Dr. Coplan was an NIH Postdoctoral Fellow at the Universite de Paris, and from 1965-1967 he was a Research Associate at the University of Chicago. In 1967, he moved to the University of Maryland where he was a Research Assistant Professor, becoming a Research Associate Professor in 1972. He became a Research Professor in 1981. He was the Director of the Chemical Physics Program at Maryland from 1985-1988 and has served in that capacity since 1996. Additionally, he has been a Guest Professor at the University of Bern (1979-1980), a Visiting Scientist at CNEN, Frascatti (1980) and a Visiting Professor at the University of British Columbia (July, 1985).

Among his many honors, Dr. Coplan belongs to Phi Beta Kappa (1960) and Sigma Xi (1963) and is a Yale University Graduate Fellow (1961). Dr. Coplan is a recipient of a NASA award for contributions to the ICE Mission (1986), a recipient of a NASA Group Achievement Award (1979), a Fellow of the American Physical Society (1995) and a recipient of the CMPS Excellence in Teaching Award (1998).

### Selected Publications


Coplan, M.A., J.H. Moore and C.C. Davis, Building Scientific Apparatus, Revised 3rd Edition, Westview Press, 2003, 549 pages.

Coplan, Michael A.,“Coincidence Techniques”, in Encyclopedia of Chemical Physics and Physical Chemistry, J. H. Moore and N. D. Spencer, eds., Institute of Physics Publishing, 2001, pp.1227-1244.

Keller, J.W., D.J. Chornay, F.H. Hunsaker, K.W. Ogilvie and M.A. Coplan, A Gated Time-of-Flight Plasma Composition Analyzer for Space Physics Research, Rev. Sci. Instr., 70, 3167-3172, 1999.

Coplan, M.A., F. Ipavich, J. King, K.W. Ogilvie, D.A. Roberts and A.J. Lazarus, Correlation of Solar Wind Parameters between SoHO at L1 and Wind, J. Geophys. Res., 106, 18,615-18,624, 2001.

Robert E. Johnson

## Biographical Summary

Dr. Robert E. Johnson is currently the J.L. Newcomb Professor of Engineering Physics at the University of Virginia. He received his B.A. in mathematics from Colorado College in 1961, his M.A. in physics from Wesleyan University in 1963, and his Ph.D. in physics from the University of Wisconsin in 1968. From 1968-1969, he was a Research Fellow at The Queen's University of Belfast in the Department of Applied Mathematics and Theoretical Physics. He served as an Assistant Professor at Southern Illinois University in Physics from 1969-1971 and at the University of Virginia in Engineering Physics from 1971-1977. From 1977 through 1984, he was an Associate Professor of Engineering Physics at the University of Virginia, becoming a Professor in 1984. He served as Assistant Dean for the School of Engineering and Applied Science at the University of Virginia from 1982-1985 and became the John Lloyd Newcomb Chair in Engineering Physics and Materials Science in 1991, a post he still holds. In January of 2000, he received an Honorary Doctorate from Uppsala University.

His prolific publication record includes about 170 refereed papers, ten chapters and two monographs.

### Selected Publications


Johnson, R. E., R.W. Carlson, J. F. Cooper, C. Paranicas, M. H. Moore, M. Wong, Radiation Effects on the Surfaces of the Galilean Satellites. In Jupiter - The Planet, Satellites and Magnetosphere, ed. F. Bagenal, T. Dowling, and W. B. McKinnon, Cambridge University Press, Cambridge in press, 2003.

McGrath, MA, E Lellouch, D.F. Strobel, P. D. Feldman, R. E. Johnson, Satellite Atmospheres, in Jupiter-The Planet, Satellites and Magnetosphere, ed. F. Bagenal, T. Dowling, and W. B. McKinnon, Cambridge University Press, Cambridge, in press, 2003.

Carlson, R.W., M.S. Anderson, R.E. Johnson, M.B. Schulman, and A.H. Yavouian, Sulfuric Acid Production on Europa: The Radiolysis of Sulfur in Water Ice, Icarus 157, 456-463, 2002.

Johnson, R.E., Surface Boundary Layer Atmospheres, chapter in Atmospheres in the Solar System: Comparative Aeronomy, Geophysical Monograph, 130, pp 203-219, 2002.

Johnson, R.E., F. Leblanc, B.V. Yakshinskiy and T.E. Madey, Energy Distributions for Desorption of Sodium and Potassium from Ice: the Na/K ratio at Europa, Icarus, 156, 136-142, 2002.

Leblanc, F., R.E. Johnson and M.E. Brown, Europa's Sodium Atmosphere: an Ocean Source?, Icarus, 159, 132-144, 2002.

Paranicas, C., B.H. Mauk, J.M. Ratliff, C. Cohen, and R.E. Johnson, The ion enviroment near Europa and its role in surface energetics, Geophys. Res. Lett., 29, 18-1 - 4, 2002.

Johnson, R.E., Surface Chemistry in the Jovian Magnetosphere Radiation Environment, in Chemical Dynamics in Extreme Environments (R. Dessler, Ed), Adv. Ser. In Phys. Chem., World Scientific, Singapore 11, Chap. 8, 390-419, 2001.

Shematovich, V.I. and R.E. Johnson, Near -Surface Oxygen Atmosphere at Europa, Adv. Space Res., 27,1881-1888, 2001.

**<u>LIST OF CURRENT AND PENDING SUPPORT</u>**

<u>Principal Investigator: Michael R. Collier</u>

A. Current Support
none

B. Pending Support

1. In-Situ and Remote Sensing of the Jovian Environment Using Low Energy (1 eV-4 keV) Plasma and Neutral Atom Imaging (this proposal)
   NASA High Capability Instuments for Planetary Exploration
   $401 K (10/1/04-9/30/07)
   0.10 years

2. Search for the Source of Mysterious Bursty Magnetic Field Wave Activity at 1 AU and Throughout the Heliosphere
   NASA Sun-Earth Connection Guest Investigator Program
   $217 K (10/1/03-9/30/05)
   0.10 years

Co-Investigator: Edward Sittler

A. Current Support

1. Cassini Plasma Spectrometer Investigation (Co-I/NASA)
   $1517K (10/97-9/08)
   0.50 years

2. Interpretation of SOHO/LASCO, EIT, UVCS Observations Using a Multidimensional MHD Model (PI/NASA/NRA-01-OSS-01 SEC)
   $248K (1/02-1/05)
   0.30 years

3. Fast 3D Ion Composition Plasma Spectrometer (PI/NASA/NRA-02-OSS-01 SECID)
   $459K (10/02-9/05)
   0.20 years

B. Pending Support

1. In-Situ and Remote Sensing of the Jovian Environment Using Low Energy (1 eV-4 keV) Plasma and Neutral Atom Imaging (this proposal)
   NASA High Capability Instuments for Planetary Exploration
   $401 K (10/1/04-9/30/07)
   0.10 years

2. Coordinated Observations of Magnetic-fields and Plasma to Address Storm Science (COMPASS) (Co-I/NASA/AO-03-OSS-02 SMEX03-0012-0024)
   (11/1/03-12/1/09)
   0.20 years

3. 3D Ion Composition Spectrometer for Planetary Missions (PI/NASA/NRA-03-OSS-01 PIDDP)
   $638K (3/1/04-2/28/07)
   0.10 years

Co-Investigator: Dennis Chornay

A. Current Support

1. Fast 3D Ion Composition Plasma Spectrometer (NRA-02-OSS-01 SECID)
   $30K/year (10/02-9/05)
   0.20 years

B. Pending Support

1. In-Situ and Remote Sensing of the Jovian Environment Using Low Energy (1 eV-4 keV) Plasma and Neutral Atom Imaging (this proposal)
   NASA High Capability Instuments for Planetary Exploration
   $401 K (10/1/04-9/30/07)
   0.13 years

Co-Investigator: John F. Cooper

A. Current Support

1. Magnetospheric Irradiation of Europa and Io
   Jovian System Data Analysis Program
   Dr. Denis Bogan, Solar System Exploration Division, (phone: 202-358-0359)
   $107K (4/23/02-4/22/04)
   0.25 years

2. Radiolytic Model for Chemical Composition of Europa's Atmosphere and Surface
   Planetary Atmospheres and Planetary Suborbital Research
   Dr. John J. Hillman, Solar System Exploration Division, (phone: 202-358-2314)
   $147K (1/1/03-12/31/04)
   0.20 years

B. Pending Support

1. In-Situ and Remote Sensing of the Jovian Environment Using Low Energy (1 eV-4 keV) Plasma and Neutral Atom Imaging (this proposal)
   NASA High Capability Instuments for Planetary Exploration
   $401 K (10/1/04-9/30/07)
   0.10 years

2. Model for Surface and Atmospheric Irradiation of Solar System Bodies in Space Environments Within and Outside the Heliosphere
   Planetary Atmospheres
   Dr. John J. Hillman, Solar System Exploration Division, (phone: 202-358-2314).
   $244K (6/1/04-5/31/07)
   0.20 years

3. Planetary Active Radio Sounder
   High Capability Instruments for Planetary Exploration
   Dr. Curt S. Niebur, Solar System Exploration Division,(phone: 202-358-0390)
   $100K (04-07, Raytheon Budget)
   0.15 years

4. Titan Orbiter Aerorover Mission
   Call for Mission Concepts: Space Science Vision Missions
   Dr. Marc S. Allen, Director, Advanced Programs and International Coordination, (phone: 202-358-2470)
   0.10 years

Co-Investigator: Michael Coplan

A. Current Support

1. Study of Electron Correlation in Atoms by Impulsive Double Ionization (NSF PHY-9987870)
   $505 K (8/15/00-3/1/04)
   0.08 years

2. Precession Time of Flight Mass Analyzer Development (NASA NAG512744)
   $47.7 K (1/15/03-1/14/04)
   0.06 years

3. Fast 3D Ion Composition Plasma Spectrometer (NASA)
   $28.5 K (3/1/03-2/28/06)
   0.08 years

4. Development and Application of Single Molecule Assays (NIST 020613-818)
   $47.5 K (4/10/03-10/10/03)
   0.00 years

5. Optical Manipulation of Bose-Einstein Condensates (NSF PHY-0100767)
   $70 K (9/1/04-8/31/06)
   0.00 years

6. Preparation and Analysis of Nucleic Acids and Proteins (NIST SB-134101C0033)
   $105 K (9/1/03-8/31/04)
   0.00 years

7. Sounding Rocket Experiment to Explore the CUSP (NASA NAG55263)
   $197 K (2/22/00-2/21/04)
   0.02 years

B. Pending Support

1. In-Situ and Remote Sensing of the Jovian Environment Using Low Energy (1 eV-4 keV) Plasma and Neutral Atom Imaging (this proposal)
   NASA High Capability Instuments for Planetary Exploration
   $401 K (10/1/04-9/30/07)
   0.10 years

2. Experimental Investigation of Two-Electron Momentum Densities (NSF)
   $450 K (1/1/04-12/31/06)
   0.08 years

Co-Investigator: Robert E. Johnson

A. Current Support

1. Ion Collision Cross Sections (NASA Planetary Atmospheres)
   $80K/year (1/02-05)

2. Radiolysis of Icy Outer Solar System Surfaces (NSF Astronomy)
   $42K/year (7/01-04)

3. Radiation Effects in the Outer Solar System and in the ISM (NASA Origins Program)
   $35K/year (6/02-05)

4. Radiation Effects on Ices on the Satellites of the Giant Planets (NASA Geology and Geophysics)
   (11/02-05)

B. Pending Support

1. In-Situ and Remote Sensing of the Jovian Environment Using Low Energy (1 eV-4 keV) Plasma and Neutral Atom Imaging (this proposal)
   NASA High Capability Instuments for Planetary Exploration
   $401 K (10/1/04-9/30/07)
   0.10 years

**STATEMENTS OF COMMITMENT**

Dr. Michael R. Collier
Code 692
Goddard Space Flight Center
National Aeronautics and Space Administration
Greenbelt, Maryland 20771

Dear Dr. Collier:

I acknowledge than I am identified by name as a Co-Investigator on the proposal entitled “In-Situ and Remote Sensing of the Jovian Environment Using Low Energy (1 eV-4 keV) Plasma and Neutral Atom Imaging” that is submitted by Dr. Michael R. Collier to the High Capability Instruments for Planetary Exploration Program NRA-03-OSS-01-HCIPE. I intend to carry out all responsibilities for me in this proposal. I understand that the extent and justification of my participation as stated in this proposal will be evaluated during peer review in determining the merits of the proposal.

Sincerely,

Dr. Edward Sittler
Astrophysicist
NASA/GSFC

Dr. Michael R. Collier
Code 692
Goddard Space Flight Center
National Aeronautics and Space Administration
Greenbelt, Maryland 20771

Dear Dr. Collier:

I acknowledge than I am identified by name as a Co-Investigator on the proposal entitled "In-Situ and Remote Sensing of the Jovian Environment Using Low Energy (1 eV-4 keV) Plasma and Neutral Atom Imaging" that is submitted by Dr. Michael R. Collier to the High Capability Instruments for Planetary Exploration Program NRA-03-OSS-01-HCIPE. I intend to carry out all responsibilities for me in this proposal. I understand that the extent and justification of my participation as stated in this proposal will be evaluated during peer review in determining the merits of the proposal.

Sincerely,

Dr. Dennis Chornay
Astrophysicist
NASA/GSFC

Dr. Michael R. Collier
Code 692
Goddard Space Flight Center
National Aeronautics and Space Administration
Greenbelt, Maryland 20771

Dear Dr. Collier:

I acknowledge than I am identified by name as a Co-Investigator on the proposal entitled “In-Situ and Remote Sensing of the Jovian Environment Using Low Energy (1 eV-4 keV) Plasma and Neutral Atom Imaging” that is submitted by Dr. Michael R. Collier to the High Capability Instruments for Planetary Exploration Program NRA-03-OSS-01-HCIPE. I intend to carry out all responsibilities for me in this proposal. I understand that the extent and justification of my participation as stated in this proposal will be evaluated during peer review in determining the merits of the proposal.

Sincerely,

Dr. John F. Cooper
Astrophysicist
NASA/GSFC

Dr. Michael R. Collier
Code 692
Goddard Space Flight Center
National Aeronautics and Space Administration
Greenbelt, Maryland 20771

Dear Dr. Collier:

I acknowledge than I am identified by name as a Co-Investigator on the proposal entitled "In-Situ and Remote Sensing of the Jovian Environment Using Low Energy (1 eV-4 keV) Plasma and Neutral Atom Imaging" that is submitted by Dr. Michael R. Collier to the High Capability Instruments for Planetary Exploration Program NRA-03-OSS-01-HCIPE. I intend to carry out all responsibilities for me in this proposal. I understand that the extent and justification of my participation as stated in this proposal will be evaluated during peer review in determining the merits of the proposal.

Sincerely,

Michael Coplan
Professor
The University of Maryland

Dr. Michael R. Collier
Code 692
Goddard Space Flight Center
National Aeronautics and Space Administration
Greenbelt, Maryland 20771

Dear Dr. Collier:

I acknowledge than I am identified by name as a Co-Investigator on the proposal entitled “In-Situ and Remote Sensing of the Jovian Environment Using Low Energy (1 eV-4 keV) Plasma and Neutral Atom Imaging” that is submitted by Dr. Michael R. Collier to the High Capability Instruments for Planetary Exploration Program NRA-03-OSS-01-HCIPE. I intend to carry out all responsibilities for me in this proposal. I understand that the extent and justification of my participation as stated in this proposal will be evaluated during peer review in determining the merits of the proposal.

Sincerely,

Robert E. Johnson
John Llyod Newcomb Professor
Head, Engineering Physics
University of Virginia

**THREE YEAR BUDGET SUMMARY**

| | | FY05 | FY06 | FY07 |
|---|---|---|---|---|
| 1. Salaries: | Collier (Civil Service) | (\$12.5K) | (\$12.8K) | (\$13.1K) |
| | Sittler (Civil Service) | (\$ 6.3K) | (\$ 6.4K) | (\$ 6.5K) |
| | Chornay (Univ. of Maryland) | \$16.9K[1] | \$16.4K[1] | \$16.4K[1] |
| | Cooper (Raytheon) | \$ 7.4K | \$ 8.9K | \$ 9.9K |
| | Coplan (Univ. of Maryland) | \$15.5K[1] | \$15.0K[1] | \$15.0K[1] |
| | Johnson (Univ. of Virginia) | \$20.0K[1] | \$20.0K[1] | \$20.0K[1] |
| | Rozmarynowski (Civil Service) | (\$11.0K) | (\$11.5K) | (\$12.0K) |
| | Total Salaries: | \$ 89.6K | \$ 91.0K | \$ 92.9K |
| 2. Equipment/Fabrication Costs: | | | | |
| | Univ. of Maryland[1] | \$ 3.8K[1] | \$ 1.8K[1] | \$ 1.8K[1] |
| | Charged Particle Rejector/Collimator | \$ 3.0K | | |
| | Heater/Conversion Surface | \$ 3.0K | | |
| | Surface Polishing and Measurement | \$ 3.0K | | |
| | Cesium Dispensers | \$ 1.0K | | |
| | Electrostatic Analyzer | \$ 4.0K | | |
| | TOF Subsystem | | \$ 5.9K | |
| | MCPs and Housing | | \$ 4.0K | |
| | Anodes | | \$ 1.0K | |
| | Fast Preamps | | \$ 5.0K | |
| | Plating | \$ 1.0K | \$ 1.0K | |
| | Misc. Lab Supplies | \$ 2.0K | \$ 2.0K | \$ 2.0K |
| | Total Equip/Fab: | \$20.8K | \$20.7K | \$ 3.8K |
| 3. Publication Costs | | | | \$ 4.3K |
| 4. Travel | | (\$ 2.0K) | (\$ 2.0K) | (\$ 2.0K) |
| 5. General and Admin. (G&A) Assessments | | \$22.8K | \$23.2K | \$24.1K |
| 6. Taxes - Lab and Directorate | | \$ 5.8K | \$ 5.8K | \$ 5.8K |
| 7. Full Cost Less Direct Labor | | \$109.2K | \$110.0K | \$ 99.3K |
| 8. Fully Costed | | \$141.0K | \$142.7K | \$132.9K |

[1]See attached budgets from the University of Maryland and the University of Virginia for a break-down of this component of the GSFC budget.